UNIVERSITAT POLITÈCNICA DE CATALUNYA

MASTER THESIS

Optimal energy planning of a rural community in Jharkhand

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Declaration of Authorship

I, Vidal CONEJO GARCÍA, declare that this thesis titled, “Optimal energy planning of a rural community in Jharkhand” and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

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Abstract

Escola Tècnica Superior d'Enginyeria Industrial de Barcelona

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Màster Universitari en Enginyeria Industrial

Optimal energy planning of a rural community in Jharkhand

by Vidal CONEJO GARCÍA

Globally, the poor in rural areas without access to electricity continue to struggle with serious challenges. These include health issues, limited educational opportunities, biomass cooking fuels contributing to poor health, poor nutrition, water availability, livelihood challenges and economic poverty. The United Nations (UN) has recognized these challenges and has officially transcribed into the Eight Millennium Development Goals (MDGs), later becoming the seventeen Sustainable Development Goals (SDGs). The seventh of the SDGs is to ensure affordable, reliable, sustainable and modern energy to all.

With that in mind, many governments, organizations and researchers have been focusing their work on finding ways to provide energy to underdeveloped communities, especially in the form of electricity. Despite the efforts, still nearly 1.2 billion people worldwide lacked electricity in 2014. More than eight out of ten people without access to electricity live in rural areas, so being most of the communities without electricity rural, rural electrification has aroused plenty of attention.

The thesis presents a rural electrification project developed in Dewgain, a community from the Jharkhand State in India. Dewgain is already connected to the electrical grid, but as many other rural communities in Jharkhand, the electric service is far from reliable.

Two visits were conducted at the village for data acquisition. The methodology followed during the visits is presented, while the analysis of the results sets the basement for the design of the solution. From the visit outcomes load profiles of the electrical consumption expected are obtained.

Based on the most accessible renewable resources from the region, a hybrid solar photovoltaic and biomass rice-husk gasifier generation system is dimensioned. Using market-available components and state of the art technologies an optimisation process is presented for dimensioning the system.

The resulting optimised design is validated matching the generation with the expected demand. Finally, the costs of implementation and operation of the solution are presented, in a 20 years service life projection.

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List of Abbreviations

AC	**A**lternating **C**urrent
AEEP	**A**frica-**EU** **E**nerggy **P**artnership
ARE	**A**lliance for **R**ural **E**lectrification
BM	**B**io **M**ass
CFL	**C**ompact **F**luorescent **L**ight bulb
DC	**D**irect **C**urrent
EIA	**E**nvironmental **I**mpact **A**ssessment
IEA	**I**nternational **E**nergy **A**gency
ISF	**I**ngeniería **S**in **F**ronteras
JREDA	**J**harkhand **R**enewable **E**nergy **D**evelopment **A**gency
LED	**L**ight- **E**mitting **D**iode
MDGs	**M**illennium **D**evelopment **G**oals
MPPT	**M**aximum-**P**ower **P**oint **T**racker
NPC	**N**et **P**resent **C**ost
PV	**P**hoto **V**oltaic
SDGs	**S**ustainable **D**evelopment **G**oals
UN	**U**nited **N**ations
UNDP	**U**nited **N**ations **D**evelopment **P**rogramme

List of Symbols

A	days of autonomy	d
ADL	average daily load	W h
BM_C	hourly maximum fuel consumption	kg/h
BM_{WH}	daily working hours of the BM plant	h
$C_{t,j}$	expected cost during the period *t* for the *j* combination of components	Rs.
DoD	maximum allowance depth of discharge	%
E	daily energy requirement for battery sizing	W h
E_{BM}	daily energy requirement for BM plant sizing	W h
E_{day}	day-time energy requirement	W h
$E_{day,total}$	total daily daytime energy requirement	W h
E_{night}	nocturnal energy requirement	W h
$E_{night,total}$	total nocturnal energy requirement	W h
$ESSH$	equivalent hours of sunshine	h
FC_{day}	daily fuel consumption	kg
g	gravity acceleration	9.81 $\mathrm{m/s^2}$
h	head available at the location	m
n	number of battery branches	
N_{batt}	total number of batteries	
$N_{charger}$	number of chargers required	
N_G	total number of rice husk gasifiers	
N_{PV}	total number of PV panels	
NPC_j	net present cost for the *j* combination of components	Rs.
$P_{AC,rated}$	rated AC power of the inverter	W
$P_{max,charger}$	maximum output charger power	W
Q	flow rate from the water source	$\mathrm{m^3/s}$
Q_{batt}	capacity of the battery required	A h
$Q_{batt,s}$	single battery capacity	A h
r	annual interest rate	%
t	year considered	
T	project life total number of time periods	years
V	system voltage	V
V_{batt}	single battery voltage	V
W_{BM}	capacity of the BM plant	W
$W_{BM,r}$	capacity of the BM plant required	W
W_g	single gasifier capacity	W
W_{hydro}	available hydro power	W
W_{pv}	single panel power peak	W
W_{PV}	peak wattage of the solar PV array	W
$W_{PV,batt}$	peak wattage of the array for supplying the batteries	W
$W_{PV,daytime}$	peak wattage of the array for supplying the daytime energy	W
Z_i	optimal overall project cost for the *i* combination of	

	generating technologies	Rs.
Z_{month}	set of minimum NPC for the month	Rs.
Z_{worst}	optimal overall project cost for the worst month	Rs.
η_{cable}	cable efficiency	%
η_{inv}	inverter efficiency	%
$\eta_{sys,daytime}$	daytime system efficiency	%
$\eta_{sys,overall}$	total system efficiency	%
ρ	water density	1000 $\mathrm{kg/m^3}$

To Marta

Chapter 1

Introduction

1.1 Motivation and project origin

The main motivation of the following project has been the interest in renewable energy sources, and specially the potential of these technologies to provide electricity to underdeveloped communities or to make viable the transition of already electrified communities into more sustainable models. On the other hand the optimisation of the energy planning, from a generation dimensioning point of view, offers the possibility of estimating the costs of the electricity generation systems on an early stage of the projects. This information can be key when looking for funding of such projects or to define the feasibility based on the community's possibilities.

Apart from these factors of interest, the project has had other motivations:

- First, it includes a field work experience in an Indian rural community. Thus, offering the opportunity of being in contact with a very different reality and gaining awareness of the actual situation that many communities are facing. Understanding the difficulties that people are experiencing and realizing in which way technology can provide them feasible solutions has been a big source of motivation.
- Second, working together with collaborators of the Amrita SeRVe organization and with the perspective that the project will become a reality in the near future has also been a great source of motivation. Being able to identify the people who will benefit from the project and feel their support and enthusiasm during the study process has been really exciting.
- Third, studying the state of the art of the different viable technologies and what are the current options that exist in the market has brought more insight on an economic sector already interesting. These technologies were not absolute strangers due to the broad (but superficial) aspects about the energy sector that during the degree and master's have been covered. Therefore, deepen on such technology aspects has also been motivating.
- Finally, participating in an international exchange program during 6 months has been very enriching and a personal growth experience. Being aware of the differences between both institutions, *Amrita Vishwa Vidyapeetham*[1] and *Universitat Politècnica de Catalunya*[2], it has been a challenge as well as a motivation to capture the knowledge acquired during these years.

[1] https://www.amrita.edu/

[2] http://www.upc.edu/?set_language=en

1.2 Objectives and scope

The project is intended to achieve several objectives:

- First of all, to present the methodology followed during the field work at the rural community, in order to serve as a reference point for future energy studies of similar communities.
- To present the results obtained through the field work and the analysis of the data conducted. Thus, characterizing the problem of study and clearly stating the energy needs from the community.
- To design a specific solution technically viable at the current state of technology and dimensioned to cover the energy needs previously identified. For this purpose, components available in the market with real prices have been used for obtaining a realistic magnitude of the costs.
- To optimize the design from a cost and performance point of view and validate the final result. The system will be valid only if the generation is capable to match the demand under all the different circumstances to which the system will be subjected.

It is necessary to say that the scope of the project is limited to the dimensioning of the system from the generation point of view. The financial viability of the project, as well as the specific selection of components and service pricing proposals, will have to be studied at a later stage.

1.3 State of rural electrification and project contributions

Globally, the poor in rural areas without access to electricity continue to struggle with serious challenges. These include health issues, limited educational opportunities, biomass cooking fuels contributing to poor health, poor nutrition, water availability, livelihood challenges, economic poverty. The United Nations (UN) has recognized these challenges and has officially transcribed into the Eight Millennium Development Goals (MDGs) [1], later becoming the seventeen Sustainable Development Goals (SDGs) [2]. The seventh of the SDGs is to ensure affordable, reliable, sustainable and modern energy to all.

With that in mind, many governments, organizations and researchers have been focusing their work on finding ways to provide energy to underdeveloped communities, specially in the form of electricity. Despite the efforts, still nearly 1.2 billion people worldwide lacked electricity in 2014. More than eight out of ten people without access to electricity live in rural areas [3], so being most of the communities without electricity rural, rural electrification has aroused plenty of attention.

Some characteristics of rural communities such as remoteness and low population density make grid extension an infeasible option for electrification. The International Energy Agency (IEA) [4] estimates that to achieve universal electrification by 2030 grid extension will represent 30 % of the cases, whereas 70 % will come from mini-grids or off-grid systems. Due to more competitive costs, decentralized generation systems (based on a single energy source or a combination of sources) have been studied as feasible options for rural electrification.

Many researchers have focused on optimizing the design of such systems, finding the best combinations of energy sources. Different renewable energies technologies have proven to be reliable solutions, although sometimes combined with diesel generators (in what literature classifies as hybrid systems). J. Bernal-Agustín and R. Dufo-López provide a broad picture on the several optimization strategies used in different studies [5].

Others, both researchers and organizations, have analysed the different possibilities that the technology can provide. Efforts such as the one presented by the Alliance for Rural Electrification (ARE) [6], the design guides by the World Bank [7] or the book edited by Springer [8] have proven to be very illustrative and useful for the project, specially during the design phase.

On top of that, initiatives as the United Nations Development Programme (UNDP) have identified the linkages between energy and sustainable development [9], in other words how energy affects the rest of SDGs, and focus their influence on country policies towards enhancing the energy access and the energy efficiency on a **renewable energy** basis. On the other hand, some organizations with a great expertise on the sustainable development field present extensive case studies of different initiatives with the knowledge that they have provided [10], as well as the lessons learned through the implementation of hundreds of mini-grid projects [11]. Also the risks related with mini-grids management have been discussed in detail [12].

In front of such a broad existing field of knowledge, the following project exposes a case study from the beginning. Since the initial planning phase of the field work and the analysis of the results obtained, through the design of the technical solution and the optimization and validation of the system.

Chapter 2

Fieldwork Research

Usually, the energy management is seen simply as the provision and installation of technologies or energy infrastructures, expressed as: percentage of electrified communities, number of distributed solar cookers, number of small hydro-power plants installed, etc.

This point of view, instead of considering the services that the community needs, is mentioned in the literature as the main failure cause of a lot of projects that have provided energy facilities to communities without a proper energy needs identification study.

That is the reason that makes the first stage of a rural electrification project critical. To try to broaden the scope of the project, the initial site survey will be based on 3 aspects:

- Energy needs identification and total load assessment.
- Identification and measurement of available energy resources.
- Social and environmental aspects.

To get a truly representative results of the community study and a real engagement from the villagers with the different project phases therefore achieving a successful and long-term sustainable solution, a participatory approach is essential. Understanding participatory approach as the process by which communities or different social sectors, especially the marginalized or excluded, with legitimate interests in a development project, program or policy, influence them and are involved in the decision-making and in the management of resources, being thus actors of its own development.

What is the best way to achieve this participatory approach might be a question for sociologist specialists, again consulting the literature gives a good base to design the site survey operational methodology:

"The identification of energy needs should not be carried out by means of a questionnaire. It is convenient, however, to use a check-list to assist the informal process of obtaining data. In this way, *the study can discover the interests of the population in their own language or point of view, while ensuring that issues of interest to energy planners are being addressed*. Particular care must be taken not to forget the marginalized groups in the community, including women and the lowest social groups" [13].

Taking the aforementioned into account, the goal of this chapter is to present the check-list to be used in the site survey, to guide the informal process of obtaining data from the community regarding the 3 previously listed main aspects.

2.1 Community under study

The identification phase will determine what is the existing demand for new energy sources. It should answer questions such as:

- How much energy is needed?
- Where is it needed?
- How is it needed? (mechanical, heat, cooling, electrical)
- Is there a real capacity and willingness to pay for the new energy supply? And to take charge of maintaining the technology by the community?
- What disadvantages can the new system entail? For example job losses.
- By what methods can the new energy supply benefit the most disadvantaged in the community?

In order to better specify the different levels of detail, the following is a guide that can be used for a correct identification prior to the implementation of an energy system [14].

2.1.1 Inhabitants

The goal of this section is to identify the different types of people and its number, so that all the groups are included in the study, even the minority and marginalized groups:

- Farmers (people working in agricultural activities).
- Women with monetary income, without income.
- Average number of sons and daughters per family.
- Elderly.
- Less favoured groups (people with chronic disabilities, extremely poor).
- Professionals (teachers, doctors, officials).
- People who only spend part of the year on the village or community.
- Visitors/tourists.
- Which are the characteristic activities from each group?
- Has there been any change in the population? People who have immigrated or emigrated and why.

2.1.2 Local institutions

A list of the local institutions that could be involved in an energy project is created. It is interesting to know what their capacities are, their experience, since when they work and what status they have within the village or community.

- Private businesses.

- Societies.
- Banks.
- Government offices.
- Volunteer organizations, NGOs.
- Religious communities.
- Technical Workshops.

2.1.3 Local organizations

It is important to identify the way the community organizes in order to carry out their everyday affairs. The following characteristics should be identified:

- Organization types: charity associations, peasant associations, government projects, women groups, professional organizations and related with economic activities.
- For how long has the organization been in operation?
- Has it been successful?
- How are they managed? Do they keep accounting and log books?
- Is the organization able to undertake activities related to the new energy installation?

2.1.4 Entrepreneurs and local businesses

It is important to identify the energy usages that generate incomes in the community.

- Actual energy services needed by the different existing businesses in the village.
- Businesses capacity to adopt the new energy options or to develop new economic activities based on the new energy source. How much energy they would need?
- On existing economic activities, the following data should be collected: financing and maintenance, means of collecting fees (for services), conflict resolution, employment policies and extension of benefits to marginalized groups.
- Will the new energy source have a negative impact in the businesses, as loss of clients, loss of jobs, damage to raw materials, etc.?
- Is a business capable of managing the new energy service? Who will hire the operators, keep the accounting, maintain the inventory of spare parts, collect the fares, etc.?

2.1.5 Local services

Some communities already have shared energy usages (as communications or refrigeration in a health centre). Their actual energy needs and required energy services must be identified.

- Schools
- Clinics or health centres

2.1.6 Other local energy facilities

Finally, it is important to ensure that the energy supplied is coordinated with other developments within the community and the area. In particular, it is necessary to identify:

- Which other development facilities are appearing in the village?
- Similar energy facilities in the neighbouring villages or communities.

2.1.7 Social and environmental aspects

In these type of projects, the evaluation of social and environmental impacts is of special relevance, in addition to economic ones, since they condition the sustainable human development opportunities of the communities.

In order to carry out the social impact study, in the identification phase, a detailed knowledge of the current or baseline situation (baseline) on which the project is intended to influence, as well as future forecasts of change, is especially important. The collection of information can be made simultaneously with the identification of energy needs.

Together with the study of social impact, the environmental impact assessment (EIA) remains an indispensable tool, both for the comparison of options and technological alternatives (complementary also to the economic-financial study), and for the assessment of the overall impact the project will have in the community life.

Finally, it is advisable to identify and assess those factors that may compromise the success of the project, which will allow to evaluate if it is viable from all possible perspectives: economic, social and environmental.

Social impact study

The primary objective of an energy supply project in rural areas is undoubtedly to improve people's lives through one of the basic pillars for well-being, which is access to energy. This concept is derived from the people centred approach to development, or Human Development. Then it is possible to study what impact on Human Development of the people and the community will have the project. The methodology that is presented is to study through a participatory process the baseline situation, and after it is properly identified predict the impacts that the project will generate on such baseline and evaluate them during and after the project implementation.

The *Appendix A* presents a check-list in order to facilitate the informal process of collecting information.

In addition to the current situation, it is also necessary to know the future prospects that may affect the community and anticipate possible changes that these may cause. Some factors that determine future forecasts are as follows:

- Existence of a National Plan for the Eradication of Poverty or similar plans that encourage investments in development and fight against poverty.
- Existence of grid extension plans (when will the grid reach the community?) Or national rural electrification plans.
- Existence of investment plans and infrastructures (will new schools, health centres, road infrastructure, etc.. be created?).
- Human Development Projects that are in process or will be started in the area.
- In relation to politics and decision-making bodies: Will there be changes in the political organization and / or decision makers? When? What forecasts are there?

Following the check-list for the establishment of the baseline we can predict the impacts of the project from the forecast in the changes of those parameters and evaluate them during and at the end of the project or program.

Environmental impact assessment

The Environmental Impact Assessment (EIA) is an important management tool for ensuring optimal use of natural resources for sustainable development. Although EIA has now been made mandatory under the Environmental Protection Act, 1986 for 29 categories of developmental activities involving investments of Rs. 50 crores and above, is highly recommended to include it in a rural electrification project, even if it has not such a high budget.

The main aspects that the EIA has to cover are:

- Project description, as the main source to identify the potential impacts.
- Definition of the scope of the assessment (it has to be bigger than the project directly affected area).
- Environmental valuation and inventory, in other words to know the environment affected and understand its actual behaviour.
- Impacts prediction, characterized (described), ranked by an impact severity value on the environment and evaluated in a global way.
- Alternatives comparison, if there are more than one alternative now is the time to choose the best (for example based on a multi-criteria analysis, where critical environmental impacts might invalidate some alternatives).
- Corrective measures, once the alternative is chosen define how the impacts can be mitigated.
- Monitoring and surveillance plan, for verification, compliance and effectiveness of EIA measures.

TABLE 2.1: Barriers analysis

Barriers type	Which are detected?	Can they be overcome? How?
Technical		
Economical and financial		
Market		
Institutional		
Social		
Political		
Environmental		

Factors influencing success

In the identification phase of the project, it is essential to analyse the barriers that are expected to be encountered. It is a question of analysing the weaknesses and threats, in order to initiate strategies that allow to overcome or to minimize the effects of the first ones and to be aware of the second ones. In the extreme case, certain barriers may make the project infeasible and rejected. To perform the analysis of the barriers it is proposed to use the Table 2.1

2.2 Grid characterisation

This section aims to identify the electrical grid situation. Identify the reasons why the grid is not working and how bad the situation is. In order to do that two different approaches are followed:

- Contact the local authorities. Request official information about the grid situation. Any data about load shedding hours, or days per month or whichever time horizon is applicable. Request the total load connected, number of houses connected to the electrical grid and un-electrified areas. Ask for feeder voltage profile. Get a layout of existing distribution system/feeders.
- Conduct on site measurements. Measure the voltage drop from different points of the grid, basically identifying how far from the feeder is the measured point. Draw a map of existing distribution system if the authorities don't facilitate one. Measure the voltage feeder profile. From the same point take measurements of the voltage and frequency to see how the values change over time. Assess qualitatively the load shedding hours, by including some questions aout the matter during the villagers interviews.

2.3 Energy needs identification

2.3.1 Energy consumption patterns in the village or community

This section identifies the present patterns of consumption, including the use of fuel, and the energy needs forecast.

- Type of fuel used (wood, manure, kerosene, etc.).
- What are the restrictions on access to such fuels: access, cost, collection work, difficulties in its use, etc.
- What are the connection to the grid near future plans?
- What benefits for the village could represent a new energy source?
- What changes in consumption patterns are expected in the next five years?

2.3.2 Homes and individuals

To assure the energy consumption patterns in the particular area have been correctly identified, the study should be as accurate as possible in the following points:

- Number of people in the homes, ages and occupations.
- Monetary incomes, non-monetary incomes, agricultural production.
- Amount of land, livestock and tools.
- Actual energy consumption patterns – traditional and commercial energy sources.
- Desire for a new energy source.
- How much they can afford to pay for the energy services?
- How could the new energy services affect the home members: men, women, children and elders?
- Will the energy demands change in the next five years?
- Is there any concern about the new energy services usage?

2.4 Total load assessment

The goal of the total load assessment is to calculate an estimate of the electrical energy that the community needs each moment of the year.

The interviews with the villagers are the main source of the data. Identifying all the electrical appliances used by each interviewed family and asking about the usage pattern of each kind of appliance. That refers to identify for how many hours each appliance is used, and at what time of the day. In addition, the future appliances are also assessed, asking the families about the electrical appliances that they would buy in the next 5 years if the electricity was correctly working.

Another important aspect for the load assessment is to identify from the first moment which appliances are used for income generation and which are used for commodity of the households. In that way the financial viability of the project can be ensured. If enough income generating activities are powered through electricity, the families will have more facilities to pay for the service.

2.5 Identification and measurement of available energy resources

2.5.1 Biomass

Biomass can be classified by its source:

- The natural, all biomass that arises spontaneously in uncultivated lands.
- The energy crops of vegetables with short cycle and high calorific value.
- Surplus (if any) of agricultural crops (mainly in Northern countries). Case apart are all organic waste, which we will generally call secondary biomass, and include all those from agricultural and livestock farms, natural areas (forest waste) or urban waste. They can be of vegetable or animal origin.

Its renewal rate is limited, it is therefore essential to talk about sustainable use. This term implies, in this context, the use of biomass sources in a way that does not compromise their future use (by depletion of the resource), while respecting the environment (avoiding the degradation of ecosystems).

For the biomass potential estimation on this project, information from the villagers will be crucial. If their agricultural or farming activities produce organic waste it will be identified and estimated the quantity of waste generated. Through standardized tables (energy obtainable per mass unit of a specific waste) the biomass potential will be determined.

2.5.2 Hydro

The calculation of the energy resource is based on two main parameters:

- The height difference (head) from the point of origin to the turbine.
- The amount of water (flow rate) that flows through the hydroelectric turbine.

$$W_{hydro} = \rho \cdot g \cdot Q \cdot h \tag{2.1}$$

where,

W_{hydro}	Available hydro power (W)
ρ	Water density, considered as a constant ($\mathrm{kg/m^3}$)
g	Gravity acceleration, constant ($\mathrm{m/s^2}$)
Q	Flow rate from the water source ($\mathrm{m^3/s}$)
h	Head available at the location (m)

For the hydro potential estimation on this project, the available head will be measured with a dumpy level or levelling instrumentation. The flow rate will be preferably measured by the container method, timing how much does it take to fill. If it is not possible, it will be estimated by the area-velocity method.

2.5.3 Solar

Solar radiation can be measured by meteorological stations that include this function, or by specific devices, known as measurement sensors, such as:

- Sun-hour meters: they do not provide the incident solar power, but the hours during which the sun has shone above a certain threshold.
- Pyranometers: are the most commonly used radiation measurement devices, they measure global solar radiation (usually on horizontal surfaces).
- Perheliometers: measure direct solar radiation.

However, in rural energy supply projects there is no need for an in-depth analysis of the different components of global solar radiation (direct, diffuse and reflected radiation) and it is not necessary to detail the irradiation hour by hour or day to Day. Instead it will normally suffice to know the average daily incident solar energy for each month.

If no measuring devices or irradiation data are available, which is the case in most of the projects, the data of the nearest meteorological station, a global irradiation database or a solar map of the area or the country can be used to estimate the solar resource potential.

It will also be necessary to consider the available area to install solar panels, such as roofs and locations without shade and available to be used. This measures can be done during the fieldwork.

2.5.4 Wind

Variability is one of the most important characteristics of the wind. In order to determine the wind potential of a site, two types of factors must be taken into account:

- Spatial factors: climatic conditions of the place, orography, wind direction.
- Temporary factors: random differences in the speed of the wind according to the time at which it is analysed.

In general, it can be said that the wind resource is capable of varying greatly over short distances depending on the terrain, the height of the wind turbine tower and the roughness of the terrain. The usable wind potential varies depending on the wind speed cube, so the determination of this parameter is of fundamental importance for the exploitation of wind energy.

On site measurements can be done, using an anemometer at a similar height as the future turbine if possible, and take wind velocity and direction measurements every 10 minutes. There also exist wind maps, done using satellite information. Inputs from the villagers about near windy places should be also taken as interesting spots to study the wind potential.

2.6 Results expected

The identification will be reflected in a report that will include, as basic elements:

- A map of the village or community; showing households and productive and commercial activities.
- An inhabitants' type summary.
- A list of the institutions, organizations and local leaders.
- A report on the management of actual energy sources and future plans for the development of new sources.
- A summary of the notes taken during the interviews, highlighting the energy needs and the willingness to pay for them.
- A sector-by-sector ratio of energy service requirements (type and amount of energy required) in the village or community.
- An assessment of the ability of local organizations or entrepreneurs to manage a new local energy project (technical, financial, managerial skills and knowledge).
- An evaluation of the organizational and management systems to review their ability to raise capital for the project, collect fees, organize maintenance, etc.
- A comprehensive analysis of the actual grid situation.
- A prevision of the load demand for the next years.
- An assessment of the available resources for energy generation within the community.

The *Annex B* is an example of the planning done before the first visit to the village. It includes all the activities necessary for a complete village assessment, and the results analysed in the next chapter come from the outcomes of that successful visit.

Chapter 3

Problem Characterisation

The different visits to Dewgain village done by Amrita University members, in addition to the Amrita SERVE observations on the zone and even the villagers' claim have identified the lack of reliable electricity service as one of the major issues this community is facing.

A visit to Dewgain village was held 18th to 24th March 2017, in order to identify the magnitude of the problem and characterize the different parameters that can play a role in its solution. A second visit to the village was held 17th to 24th June 2017, which allowed to obtain more data and refine the analysis.

This chapter presents the results of both visits.

3.1 Work zone

The present energy needs assessment has been done in a rural community in the Jharkhand state, in Ranchi region (its capital). The state has 98.48% of its villages electrified [15]. Its geographical situation can be observed in Figure 3.1.

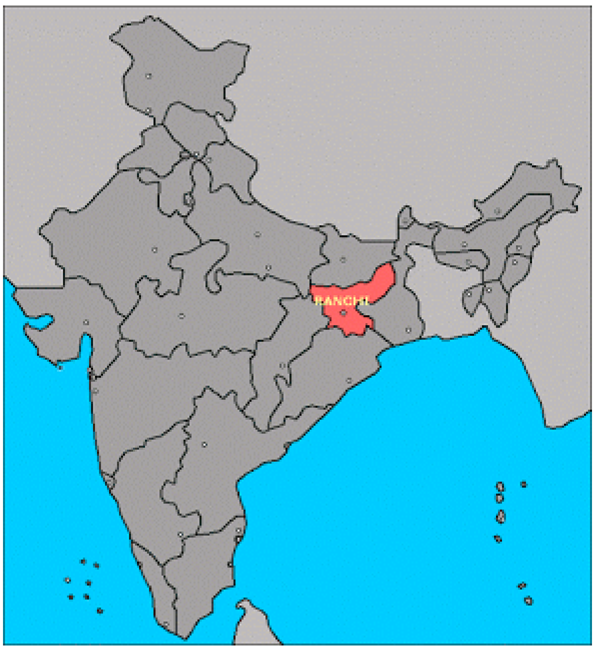

FIGURE 3.1: India map, with Jharkhand state highlighted in red.

Although this number implies almost all Jharkhand villages are electrified, other studies based on the capacity installed in the households, the daily average duration of the service, the monthly blackout days and the quality of voltage level show 73% of the state's rural population are not getting proper access to electricity. The main reasons of that situation being (in decreasing order): having no form of electricity supply, facing five or more days of black-out in a month, having less than 4 hours per day of service or having high voltage levels that damage appliances more than 3 days in a month and low voltage levels that don't let them use it's appliances more than 6 days in a month [16].

Jharkhand covers an area of 79,716 km^2 and has a population of approximately 33 million people, what represents a 2.72% of India's total population. The majority of Jharkhand's population is rural, representing 75.95% of the total.

Jharkhand is one of India's poor regions. In 2009, a 39.1% of its population was living on less than \$1.25 per day. Moreover the Human Development Index Value of Jharkhand is 0.376 (while the national average is 0.467) [17]. The main economic activities are agriculture and mining.

Dewgain village is located in the centre of Ranchi district, approximately 25 kilometre south from the capital, Ranchi. The geographical coordinates of Dewgain are: 23º13'00.6"N 85º21'45.6"E. Figure 3.2 locates Dewgain inside Ranchi district.

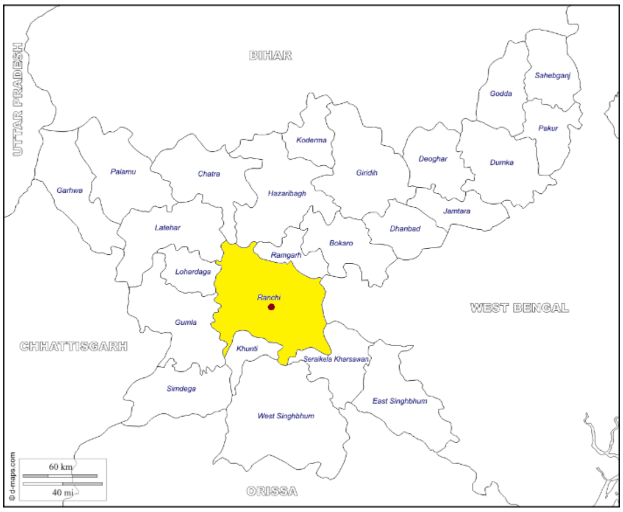

FIGURE 3.2: Dewgain village situation inside Ranchi district.

There are 194 families living in Dewgain, approximately 900 inhabitants[1]. Another source estimates the number of families as 220 and 1500 inhabitants[2]. Figure 3.3 shows the professional activities done in the village. It is clear that Dewgain is mainly a farming community. The village is divided in 3 clusters: the main one grouping 185 houses (purple cluster), while the other two have 24 (orange cluster) and 12 (green cluster) houses each one. A representation of the clusters over a satellite image is shown in Figure 3.4.

[1] AMRITA SERVE Health Survey (2015-2016).
[2] Amrita University team previous visit

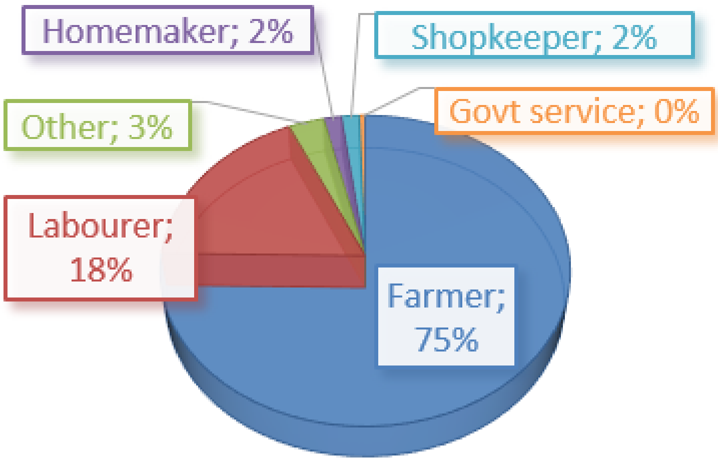

FIGURE 3.3: Professional activities done in the village.

3.2 Grid Situation

Recognizing that energy access is a multidimensional phenomenon, a measuring system was devised by the CEEW (in collaboration with US Columbia University and Shakti Sustainable Energy Foundation) to help uncover the true answers to questions regarding village electrification [16]. They formulated a graduated rating scale of 0 to 3, each weighted across six dimensions of electrification as listed below, all of which reflect measures of energy affordability, supply availability, quality, and legality of access:

- Capacity
- Duration in hours each day
- Reliability - Number of blackout days each month
- Quality (e.g., voltage fluctuations)
- Affordability
- Legality

Referencing these six dimensions, a rating of 0 represents households either with no electrification, less than four hours daily, blackouts for 5 or more days monthly, very poor quality electricity, inability to afford it, and/or illegal connections. The present grid characterisation has been done based on this rating methodology.

During the first visit, the team held two meetings with the authorities in charge of the electrical grid and realized an on-site grid assessment. The second visit included more measurements of the existing grid.

3.2.1 Authorities meetings

The first meeting was with the junior engineer responsible for the Electrical Substation that supplies Dewgain. He informed that data regarding network topology,

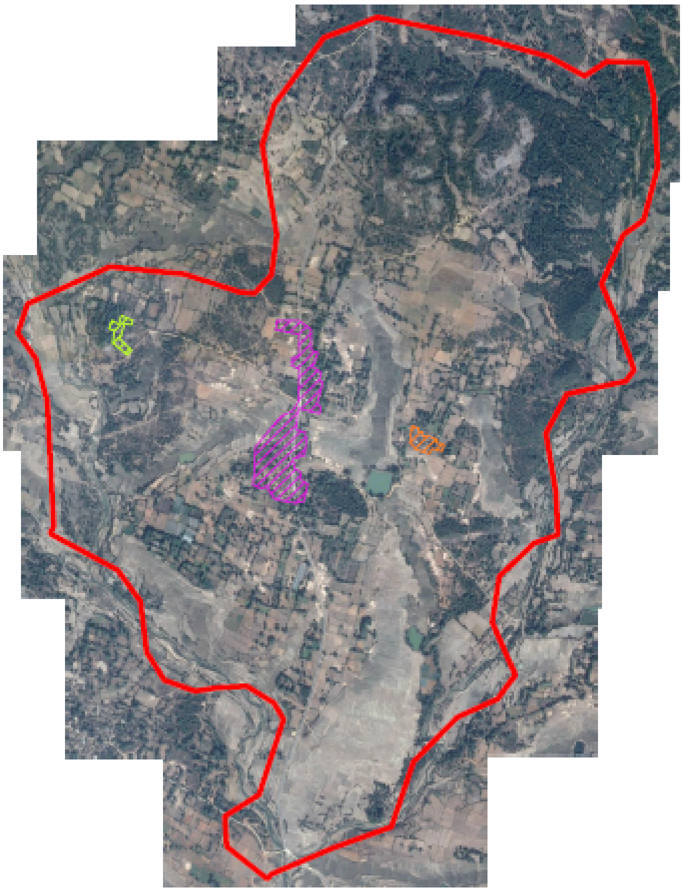

FIGURE 3.4: Dewgain village limits and its 3 clusters.

such as a feeder map, is not available for rural communities. The authorities claimed that they *"are not tracking data about load shedding, the power supplied, or the load connected to the substation."* Also, they justified the low quality service stating that *"the electrical substation is covering a larger area than the one it's designed for."*

The second meeting was at the Collector's[3] Office with the senior engineer responsible for the Ranchi District Area. As in the Electrical Substation, they had no technical data about the grid (grid map, feeder voltage profile, connected load, power supplied, load shedding data, etc.). When asked about the bills that the villagers are paying, they replied *"in rural communities the villagers pay for 8 hours of service per day. The time of the day they are getting the service is not fixed, and the 8 hours is on average."* However, our interviews with the villagers revealed that there are periods during the year when they do not receive 8 hours of electricity per day. So the community is paying for an electrical service they are not getting consistently. Further, they frequently do not receive electricity when they most need it: during evening and night hours, and during monsoon season. In terms of number of blackout days each month, the third of the 6-dimension assessment model, this would merit a Tier 0 rating.

When inquired about future plans for improving the grid in the village, the Collector's Office engineers stated that *"we plan to divide in two parts the large area serviced*

[3]The administration responsible to charge the electricity bills and other fees.

by the Electrical Substation, implementing a second substation for the other half of the territory. Also, due to the villagers' demand, we will install an extra feeder in Dewgain". When asked for a time estimation of the implementation of these projects, they did not respond. As our meetings with authorities were not fruitful in providing needed data, we carried out our own assessment of the village grid system.

3.2.2 On-site assessment

Although the unsuccessful visits to the authorities, in order to study the grid situation the team carried out an on-site assessment.

Layout Dewgain electrical grid map

First, a layout map of the electrical grid in Dewgain is presented in Figure 3.5. The layout is divided in the three clusters. Each color of the lines represents a different feeder, the street lights (incandescent light bulbs directly connected to the grid) are also included in the maps (6 light bulbs in 185 houses cluster and 3 light bulbs in 24 houses cluster).

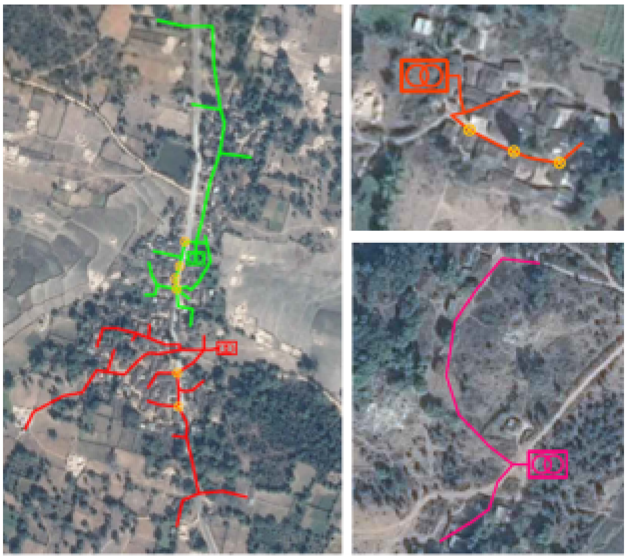

FIGURE 3.5: Electrical layout map of the village.

Each color of the lines represents a different feeder, the street lights (incandescent light bulbs directly connected to the grid) are also included in the maps (6 light bulbs in 185 houses cluster and 3 light bulbs in 24 houses cluster).

The feeder maps indicate four feeders are supplying electricity. Although independent feeders, during a load shedding it was found that the two feeders of the main cluster were not working at the same time. Thus we speculated that the four feeders are connected a few kilometres away. Also, three un-electrified houses were found, representing 1.36% of the total number of houses. That is an acceptable electrification access rating, although the capacity dimension is measured in terms of electrical appliances connected to the grid and not just if the households are connected or not.

Voltage feeder profile study

Required voltage and frequency measurements were taken from the power socket of the first house connected to the feeder from the red line feeder every five minutes, during three different time periods of the day. The time periods were 12:30 to 13:35, 18:00 to 19:20 and 22:50 to 00:00. During the second visit measurements were done between 16:20 to 18:00. Globally, the sample size is 5 hours and 45 minutes, a total of 67 measurements for each magnitude. The results are presented in Table 3.1. The graphs obtained from the measurements are included in Appendix C.

TABLE 3.1: Voltage and frequency feeder profiles

Period of time	Voltage variation	Frequency variation
12:30 to 13:35 (first visit)	2.86%	0.28%
18:00 to 19:20 (first visit)	11.98%	0.62%
22:50 to 00:00 (first visit)	2.68%	0.44%
16:20 to 18:00 (second visit)	**41.19%**	**3.77%**

The situation during the second visit was worse in terms of grid stability. These remarkable variations can damage the electrical appliances. That is the reason why for the Quality dimension of the CEEW rating system, Dewgain grid qualifies as Tier 0.

Households voltage level

The third aspect of the grid studied was the influence of the distance from the feeder on the voltage level. In order to do it the voltage level was measured in all the visits (when the electricity was working), resulting in a sample size of 73 measurements. Figure 3.6 shows the results obtained.

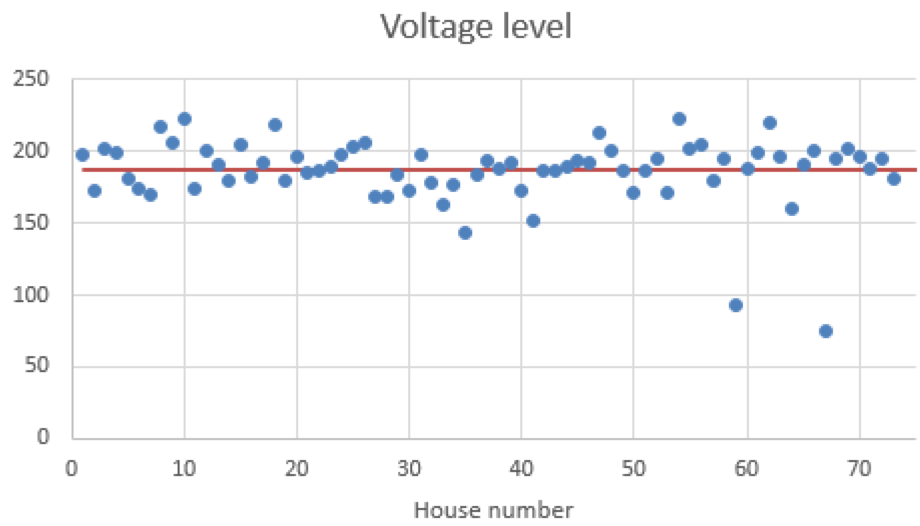

FIGURE 3.6: Voltage levels in the visited houses.

From the frequently changing voltage values ranging from 75 up to 223 V, the average voltage level was 186.5 V. Houses with high voltage levels were found far away from the feeders and houses with lower voltage values were found near the feeders, suggesting that voltage levels are not influenced by the distance from house to the feeder as usual. However, the wide range of values was heavily influenced by the distance between each house and their connections to the line.

One possible reason for inconsistent voltage levels is the cable wires, which were observed to be underrated. There was no observed standardization of cable dimension used, hence the elevated voltage drop observed in the houses farthest from the electric line (75 V and 93 V voltage level values).

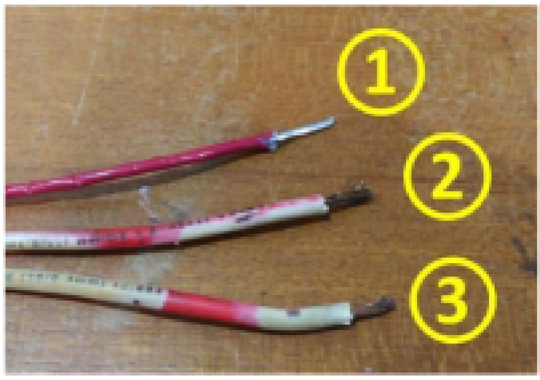

FIGURE 3.7: Sample cables collected from the village .

Some samples of these cables were collected, and their resistance values were obtained. Figure 3.7 shows the samples and Table 3.2 shows the resistance values obtained from them. It is clear from the values obtained that the cables are underrated.

TABLE 3.2: Sample cables properties

Cable nº	**Resistance (Ω)**	**Length (m)**	**R/L (Ω/m)**
1	0.6	0.22	**2.73**
2	0.3	0.98	**0.31**
3	0.4	1.08	**0.37**

Apart from these technical data, a good example of the grid unreliability is the fact that from 118 houses visited, 45 did not have electrical service during the time of the visit. This implies that 38% of the voltage measures could not be taken. Additionally, villagers consistently reported that, on average, they experience 2-4 days weekly of no power. In fact, when we arrived the village had just experienced a nearly 10-day blackout period. Further, during the monsoon season, they reported, access to power is very infrequent. Again reflecting back to the 3rd of the 6-dimension electrification assessment (Number of blackout days each month) , this would merit a rating of Tier 0, as previously mentioned.

During the second visit (at the start of the monsoon season) the grid situation was also worse in terms of duration and number of blackout days. Out of 7 days at the village, 6 of them where blackout days with maximum 1 hour of electricity. Only

1 day there was almost 8 hours of service. This coincides with the villagers' explanations during the first visit and sets the second dimension of the rating system (Duration in hours each day) to Tier 0 for the whole community.

Affordability and legality

For evaluating the last 2 dimensions of the CEEW, affordability and legality, the interviews provide the necessary data. Questions about the electricity bill, the monthly income of the families and observation of how the connection to the grid was made.

A family was qualified with an affordable service if the electricity cost was equal or less than 4% of their income. In total, 52.48% of the interviewed families (53 out of 101) could afford the electricity, therefore ranked as Tier 3 households. From the rest, 31.68% couldn't afford it (obtaining a Tier 0 grade), while 15.84% had unknown income levels.

About the legality dimension, 79 out of 101 families where legally connected to the grid and received a Tier 3 ranking. On the other hand, 22 families where illegally connected and were assigned a Tier 0 punctuation.

3.2.3 CEEW tier system results

The CEEW tier system provides a multi-dimensional approach for considering a community correctly electrified. For Dewgain village, the punctuations obtained on each dimension are presented in Table 3.3.

TABLE 3.3: Dewgain households CEEW tiers results

Dimension	Tier 0	Tier 1	Tier 2	Tier 3	Unknown
Capacity	2.97%	2.97%	**62.38%**	31.68%	0.00%
Duration	0.00%	**100.00%**	0.00%	0.00%	0.00%
Reliability	**100.00%**	0.00%	0.00%	0.00%	0.00%
Quality	**100.00%**	0.00%	0.00%	0.00%	0.00%
Affordability	0.00%	31.68%	0.00%	**52.48%**	15.84%
Legality	0.00%	21.78%	0.00%	**78.22%**	0.00%

From the results obtained within the CEEW scale systems, is clear that Dewgain is inadequately electrified. The main problems of the grid are the low reliability, the bad quality of the electricity due to its voltage instability and an insufficient daily duration of the service.

3.3 Energy Consumption

This analysis utilized several sources, from the revision of secondary information, elaboration of data collection resources, and on-site data collection. The methodological scope is based on 3 main stages:

1. Secondary information revision: sourced from a prior survey work done by Amrita SERVE NGO [18]. During 2015 and 2016 a survey was held over all Dewgain inhabitants, asking about familial economy, education and health.
2. Elaboration of data collection resources: considering a survey as a biased way to get the required information for the study, a check-list was made to cover the main topics of productivity activities, sources of income, energy demand, energy sources, energy cost, energy usage, and expected future demand. Using the check-list, semi-guided interviews were conducted with the villagers, thus we received their reports first-hand.
3. Data analysis: after having applied the instruments of data collection in the community assessment, the information was analysed and represented in tables and statistical graphs from a quantitative and qualitative point of view.

3.3.1 Families categorisation

Based on the income level of the families, two groups have been categorized: those families with incomes covering (or hardly covering) their subsistence and the families capable of having a surplus at the end of the month. A monthly income level of Rs. 5,000 or more categorizes a family in the **surplus** level, while having less than Rs. 5,000 per month categorizes the family in the **self-subsistence** level. Out of the 194 families that the Amrita SERVE Health survey reports, 47 belong to the surplus level while 147 belong to the self-subsistence level (24% and 76% respectively) [4].

The on-site assessment covered 118 houses, including 101 families reported by the Amrita SERVE study. These 101 families are categorized based on the Amrita SERVE income information, resulting in 23 surplus families, 62 self-subsistence families and 16 uncategorised families (that are not in the Amrita SERVE study).

3.3.2 Household energy usage results

The assessment identified five main energy sources used in the households. For cooking purposes families are using wood and butane, for lighting they are using electricity, kerosene and flash-lights with cells. Electricity is used for mobile charging, TV, fans and even a few irons. Minor energy sources are candles for lighting purposes and dried cow dung as fire starter.

Without segregating by income, 98% of the families are using electricity, 93% kerosene, 96% wood, 22% butane, 58% cells and 4% candles. The usage of each energy source segregated by family income is shown in Figure 3.8.

The cost of the energy was also analysed. For the wood, there is no direct economic cost, but there is an opportunity cost for the time spent for collecting it. The average time spent is 75.42 hours/month for self-subsistence level families and 76.61 hours/month for surplus families. This will contribute to an opportunity cost of 1,583.82 Rs/month for self-subsistence level families and 1,608.81 Rs/month for surplus families [21]. An important mention is that the collection work is done primarily by women. Occasionally some of them join in groups and collect wood together,

[4]This represents an even more severe level of poverty than determined by the International Poverty Index of $1.25 per day per person, or Rs. 2,400 per person per month [19] [20]. If this applied to the average Dewgain family size of 5, the poverty index would be Rs. 12,000 per month.

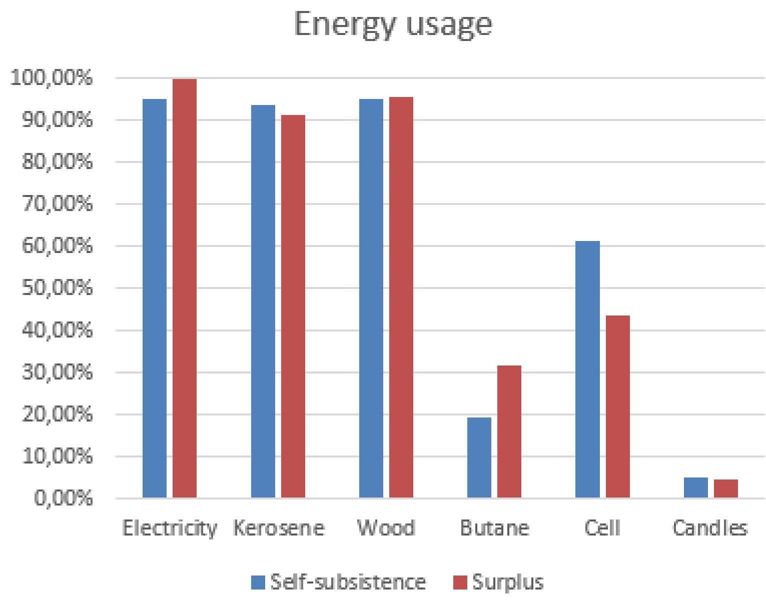

FIGURE 3.8: Energy sources used by families.

thus this activity is a social gathering. But many also collect wood individually. A few families also earn some income by selling additional wood to others. The rest of the energy sources have a direct cost associated with, as shown in Figure 3.9.

Data analysis revealed a higher monthly energy expenditure in surplus families (Rs. 364.7, or 50.5% higher), whereas self-subsistence families spend an average of Rs. 242.7 (Figure 3.10). The main cause of this difference is the use of butane as cooking fuel in higher income families. Butane is used only by 19.4% of self-subsistence families, while 31.8% of surplus families are cooking with this energy source, representing on an average more than Rs. 100 extra expenditures per month. Through family interviews, the implementation of a government scheme for increasing butane utilization was confirmed. The cost of 14.2 kg butane cylinder is around Rs. 600, which is unaffordable for most of the families [22].

3.3.3 Productive energy usage results

Different income generating activities were identified in the village including agriculture, food processing and commercial activities. Energy usage for these activities was assessed.

Regarding commercial activities, Dewgain has three grocery shops. All three use electricity for lighting and running a refrigerator. Also, two of the shops use kerosene for lighting when electricity is not available and the other shop is using a butane cylinder.

The food-processing sector consists of two rice mills that run on diesel motors consuming approximately 1.5 L of diesel every hour. They use on average 20 L of diesel per month, or Rs. 1,200 per month.

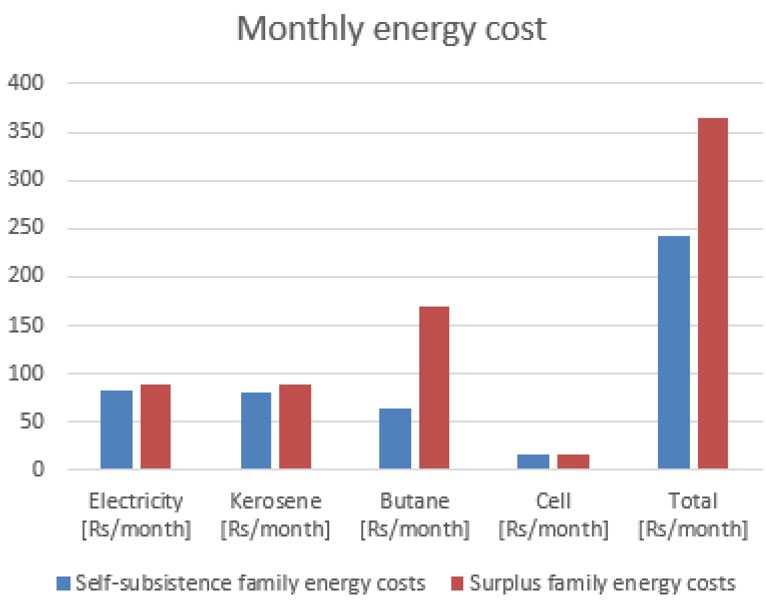

FIGURE 3.9: Monthly energy cost per family income level and energy source.

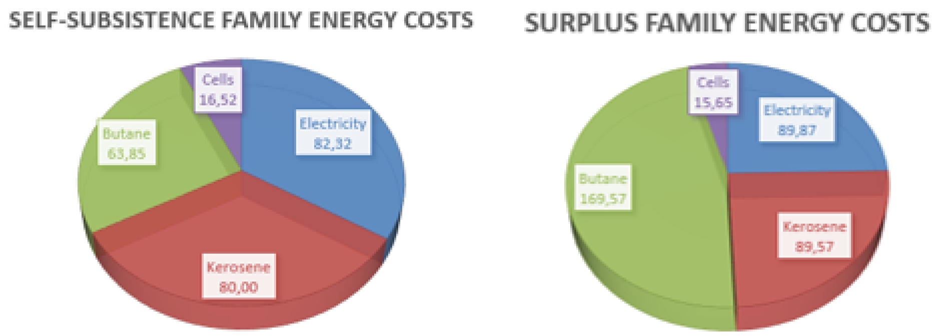

FIGURE 3.10: Average family monthly energy costs in Rs.

For agricultural activities, out of 101 interviews, 24 families reported motor usage for pumping water. 23 out of 24 families owned the motors they were using, while 1 family rents it occasionally from a shop. The motor technology usage is shown in Figure 3.11.

The operational cost is different for varying technologies. Kerosene, petrol and diesel motors depend upon the fuel price, while electric motors are dependent on plug point installation near the wells for pumping water.

Many families invested in electrical motors (56.7%), but the lack of reliable service makes it an inefficient solution. In fact, 7 out of 17 families who own electric motors (41.2%) also own kerosene or petrol motors as backup systems.

Thirty-seven families rely on monsoon rain for agriculture representing 60.6%. A reliable electric supply could encourage farmers to use electric motors for increased agricultural crops during seasons of little or no rain.

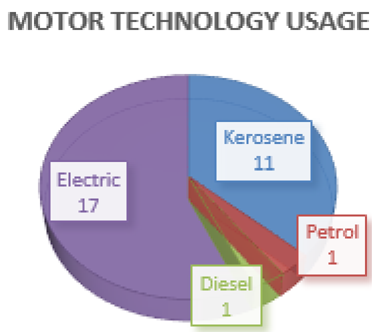

FIGURE 3.11: Number of motors of each technology used by the community.

Finally, a diesel water pumping system was found near the East river. It was installed years ago and was used by 5 families with lands near the system. Due to lack of maintenance the pumping system is not running any more since more than 15 years ago.

3.4 Load profile

The load profile was studied through the household interviews. Electrical appliances were identified within each home, and families were asked about the hours of use. Appliance data was analysed and segregated based on the income level. The different electrical appliances found in the houses were: light-emitting diodes (LED), compact fluorescent light bulbs (CFL), and incandescent bulbs for lighting, mobile phones (and chargers), T.V., fans, irons, mixers, and refrigerators.

3.4.1 Actual load

The average number of appliances used by each household was assessed, average power of each type of appliance, and average hours used daily. The daily energy required was calculated by multiplying the power, the number of appliances, and the hours of usage. Assuming similar situations for the non-interviewed families, the total number of appliances was calculated for surplus and self-subsistence families. The summarized energy consumption, categorized by appliance, is as shown in Table 3.4 and Table 3.5.

Figure 3.12 shows the importance of each type of appliance in the total energy demanded. It is clear that most of the energy demand corresponds to incandescent lighting, representing more than 67% of the household electrical energy demand. The next highest energy consumer are fans (used seasonally during the 4 summer months), representing 16% of the household demand.

Apart from the household loads, the production loads were also assessed, including electrical loads in the agricultural sector (electrical motors) and in grocery shops (for lighting purposes and refrigerators). To estimate the number of motors used in the village, was speculated that those not interviewed would have a similar distribution pattern of motors as the inhabitants from whom data was collected. For 101 families,

TABLE 3.4: Surplus families electrical appliances usage

	Quantity	**Total power (W)**	**Average use (h/d)**	**Total energy (W h/d)**
Surplus families	47			
LED	58	522	7.88	4110.75
CFL	13	182	5.67	1031.33
Incandescent	141	1410	8.08	113923.92
Mobile charger	60	360	6.00	2160.00
T.V.	31	3100	3.80	11780.00
Fan	43	3225	12.00	38700.00
Iron	8	6000	0.5	3000.00
Mixer	4	3000	0.5	1500.00
Refrigerator	6	1200	24.00	28800.00
			Total	**205006.00**

TABLE 3.5: Self-subsistence families electrical appliances usage

	Quantity	**Total power (W)**	**Average use (h/d)**	**Total energy (W h/d)**
Self-subsistence families	147			
LED	114	1040	5.98	6219.82
CFL	26	390	7.00	2730.00
Incandescent	396	40430	8.37	338570.49
Mobile charger	180	1080	6.00	6480.00
T.V.	71	7100	3.50	24850.00
Fan	76	5700	12.00	68400.00
Iron	10	7500	0.5	3750.00
Mixer	3	2250	0.5	1125.00
Refrigerator	3	600	24.00	14400.00
			Total	**466525.31**

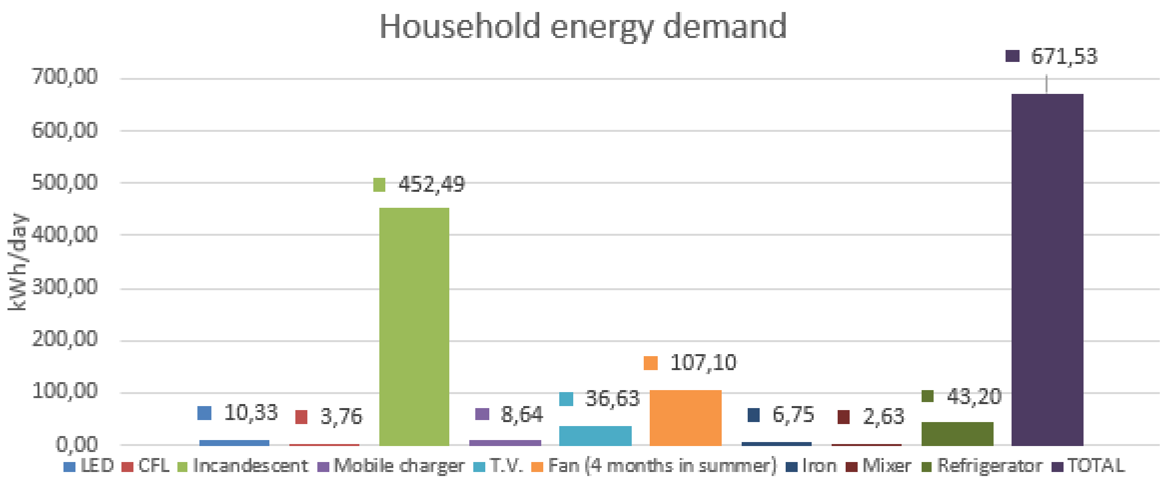

FIGURE 3.12: The summarized household energy consumption, categorized by appliance.

17 electrical motors were found, thus for the entire community (194 families) 33 electrical motors were estimated. For the grocery shops no estimate was necessary since all three shop owners were interviewed. The average electrical power demanded by these motors is 0.8 kW. The summary of the productive loads is shown in Table 3.6 and Figure 3.13.

TABLE 3.6: Productive electrical appliances usage

	Quantity	**Total power** (W)	**Average use** (h/d)	**Total energy** (W h/d)
Commercial load	3			
LED	4	52	4.50	234.00
CFL	4	60	4.50	270.00
Incandescent	3	400	4.50	1866.67
Refrigerator	3	300	24.00	7200.00
Agricultural load	33			
Electrical motor	33	26400	3.00	79200.00
			Total	**88770.67**

From the productive loads point of view, it is clear that the electrical motors demand most of the energy, as much as 79.2 kW h/d, representing 89% of the total energy used in productive appliances. The second load category, refrigerators, is seasonal (during the 4 summer months) and represents 8% of the total energy. Total energy use is represented in Figure 3.14.

During summer months the quantity of energy needed is greater due to fan and refrigerator seasonal loads. For a summer day this is about 760.3 kWh/d.

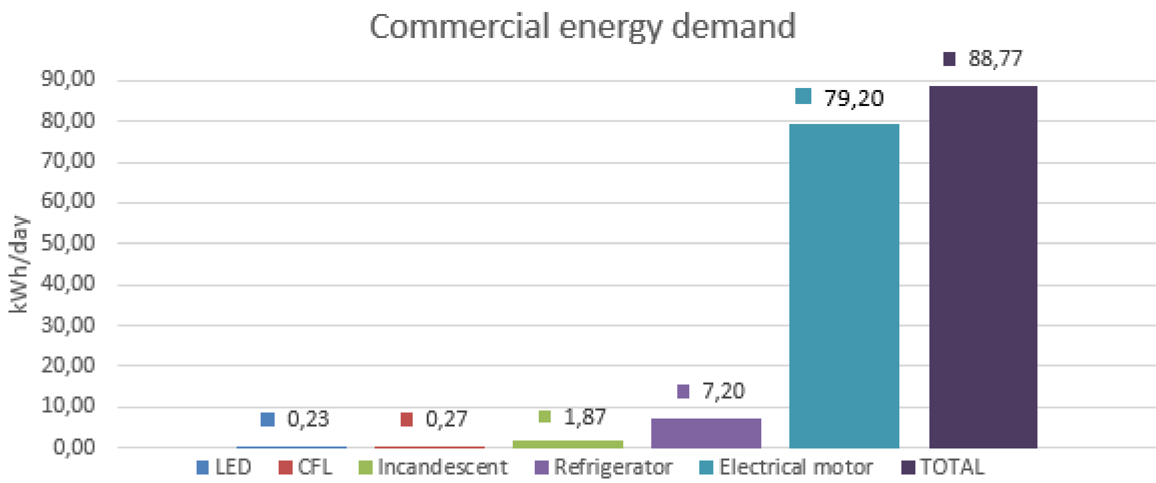

FIGURE 3.13: The summarized commercial energy consumption, categorized by appliance.

3.4.2 Future load

The interviews also covered the aspirations of community and future plans for acquiring new electrical appliances. A similar profile was estimated for the entire community. Anticipating that energy needs will increase, the new load profile can be calculated. For lighting purposes, the usage of efficient LED technology has been considered.

As Table 3.7 shows, the community is primarily focused on investing in productive use of electricity such as electrical motors or other production machines. Commodities for the houses, such as refrigerators also were common among the villagers' responses. Special attention will require the possible appearance in the village of the first induction stoves. The access to that appliance should not be encouraged, due to its high power requirements.

3.4.3 Future load profile

Once the different demands are known, and using the usage hours' data the villagers shared in the interviews, an estimate of the future load profile can be made. Hour by hour the total power needed is obtained by considering the usage or not of each load category, and what percentage of each category is used.

For example, villagers come back from work usually around 18:00 or 19:00. Therefore, the T.V. category load is considered to be used about 20% at 18:00, increasing to about 80% by 19:00, and by 20:00 it is estimated to be 100% in use. After that it is less used, 90% at 21:00, 50% at 22:00 and 10% at 23:00. In total it has been used for about 3.5 hours at 100%. Similar assumptions are taken for each load category, considering the number of usage hours and the consumption patterns that villagers explained, or that were observed during the assessment.

Additionally, load is categorised based on the reliability to pay for the energy each owner can have. This approach uses the categories anchor - business - community

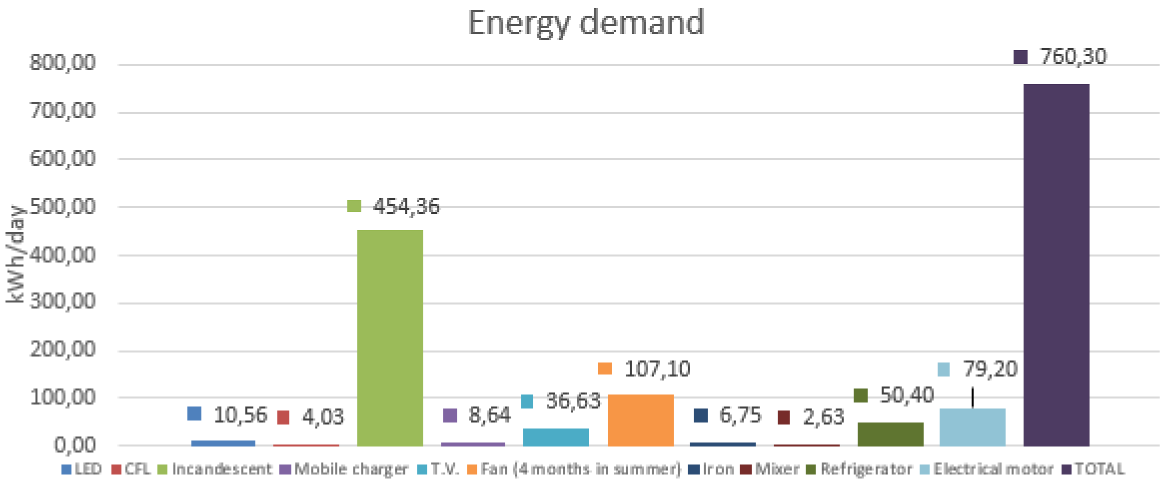

FIGURE 3.14: The summarized energy consumption, categorized by appliance.

TABLE 3.7: New electrical appliances usage

Future load	**Affirmative answers**	**Estimate number**
Electric motor	12	23
Drilling machine	1	2
Soldering machine	1	2
Tailoring machine	1	2
Fan	3	6
Induction stove	3	6
Lighting systems	13	25
Photocopy machine	2	4
Laptop	1	2
Refrigerator	5	10
Air conditioner	1	2
T.V.	2	4
Washing machine	2	4
Wood cutter machine	1	2

to get an idea on how likely is an Energy Service Company going to get income from the electricity provided [23].

For the anchor category, described as the more reliable income source, a Telecom tower recently installed in the village has been considered. Actually the tower is operated by a diesel generator, but if affordable and reliable electricity can be offered to the Telecom company, it is very likely they will connect to the grid. For the energy needs of the tower, the report from Greenpeace has been taken as a reference [24].

The business category represents the productive loads, thus if the owner is getting some income from their use he will be more able to pay for the energy. It includes all the loads from the shops, the motors and the new productive appliances.

During the second visit, extra assessment of the motors usage was done. The motor usage for pumping water into the fields was discovered as a seasonal load, closely related to the weather conditions of the region. The main crop from Dewgain is rice. The rice crop starts during rainy season (July). The first two months it doesn't require a lot of pumped water. After, during September and October it requires extra water that is obtained through the motors. Finally, during November it almost doesn't need water and December and January is the harvest. The access to a reliable electricity source can allow the farmers to obtain a second crop. As discussed with the Block Technology Manager[5], the best crop villagers could grow during the months without rice, instead of being a second rice crop, would be different kinds of vegetables. Vegetables provide a continuous small income to the farmers. They can sell them in local markets and obtain a good return rate.

Also from the interviews, the farmers reported that they only pump water during the first 5 hours of the day, from 5 a.m. to 10 a.m. With all that requirements and considerations for the motors in mind, a new estimation of the usage was done as Figure 3.15 show.

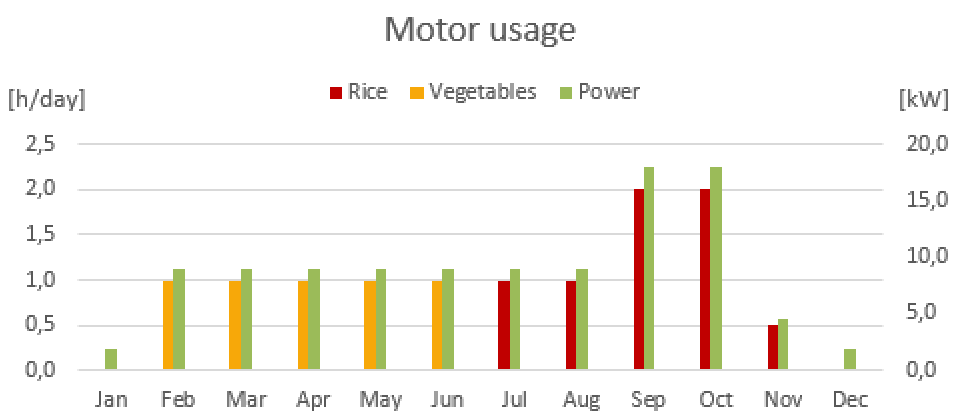

FIGURE 3.15: The hours of use and the power requirement of the motors.

Finally, apart from the appliances found in the households during the interviews and the future plans of the community individuals, a remote learning project has been considered as future community electrical load. It includes 7 grades that today are not thought at the government school, which only reaches 5th standard. Also improvements on the Health Centre equipments have been considered, including a refrigerator for medicines. The energy requirement for both facilities is shown in Table 3.8.

Last considerations applied to this future profile model were an efficient usage of the community electricity. That includes some **awareness program** for changing villagers' habits. During the visits, it was observed how they don't turn off the lights when there is no one using them. Since electricity is not reliable, they leave the lights on and that way they can realize when the grid is providing electricity. Some program should be initiated to change this behaviour and be aware of the limited electric resource there will be available. On the other hand, a cheap way

[5]The Block is the administration of the 40 neighbour villages from the region. It helps to the development of the region by implementing agricultural schemes.

TABLE 3.8: Communal electrical appliances usage

	Quantity	Total power (W)	Average use (h/d)	Total energy (W h/d)
Education	7			
LED	28	252	5.00	1260.00
Computer+Screen	7	490	5.00	2450.00
Projector	7	1750	5.00	8750.00
Speakers	7	70	5.00	350.00
Fan	14	1050	5.00	5250.00
Wi-fi router	1	20	24.00	480.00
Health Centre	1			
Refrigerator	1	200	24.00	4800.00
LED	4	36	8.00	288.00
Fan	1	75	8.00	600.00
			Total	**24228.00**

to reduce the energy needs would be **changing all the incandescent bulbs for the more efficient LED technology**. All the present 100 W incandescent bulbs have been considered to be 9 W LED instead.

The result is presented in Figure 3.16. The seasonal variations observed are product of the different motor usages through all the year and the other seasonal loads used in summer: fans and refrigerators. The *Appendix D* includes each month load profile, with the anchor - business - load classification of the loads.

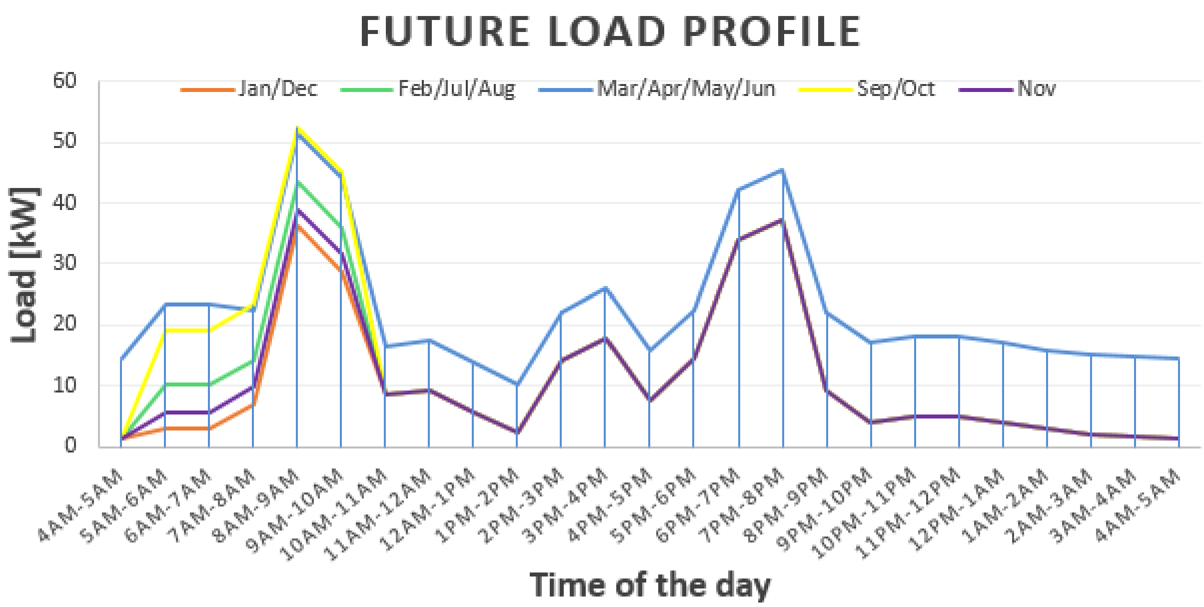

FIGURE 3.16: The future demand of energy for each hour of the day.

It can be observed how the load profile presents two peaks. The first one between 8 - 10 a.m. and the second between 6 - 8 p.m. The first one corresponds to the morning time, while children prepare to go to school and have breakfast and the second peak when the villagers are coming home for dinner after work. The variations in the morning hours are caused by the different usage of the motors, while after 11 a.m. profiles only differ on the season loads from the fans and refrigerators used during summer months (March to June). Table 3.9 shows the different values of total daily load and peak load for each month. The peak month values in the table are higher than the ones shown in Figure 3.16 because additional simultaneity of loads is considered for the business category loads as a security factor for the installation. The summer months have the highest energy need due to the seasonal loads, while September and October have the highest peak due to a major motor usage.

TABLE 3.9: Future load profile

Time period	Total daily load (kWh)	Peak load (kW)
Jan/Dec	264.22	50.83
Feb/Jul/Aug	300.22	63.01
Mar/Apr/May/Jun	549.62	71.56
Sep/Oct	345.22	85.51
Nov	277.72	51.76

An additional analysis is presented in Table 3.10. The differences between the present and the future electricity consumption in the village can be observed. The expected connection to the grid of the anchor loads and the increased usage of the business loads can be considered as an enhancement of the capacity to pay for the service. In fact, these loads give more security to the financial reliability of the project, since they are income generating activities. This load categorisation should be considered during the tariff design in order to leverage the electricity costs for the community. Finally, the effect that the awareness and energy efficiency programs will have in the reduction on the community energy needs is observed. Implying an energy need reduction of more than 49%, the convenience of these programs is demonstrated.

TABLE 3.10: Anchor, business and community loads comparison

Time period	Total daily load (kWh)	Anchor load	Business load	Community load
Present	760.30	0%	17.05%	82.95%
Future				
January	264.22	21.57%	23.54%	54.89%
February	300.22	18.99%	32.70%	48.31%
March	549.62	10.37%	19.17%	70.46%
April	549.62	10.37%	19.17%	70.46%
May	549.62	10.37%	19.17%	70.46%
June	549.62	10.37%	19.17%	70.46%
July	300.22	18.99%	32.70%	48.31%
August	300.22	18.99%	32.70%	48.31%
September	345.22	16.51%	41.48%	42.51%
October	345.22	16.51%	41.48%	42.51%
November	277.72	20.52%	27.25%	52.22%
December	264.22	21.57%	23.54%	54.89%

3.5 Resource availability

The resource availability assessment done in the village was mainly qualitative. A quantitative assessment was done in a later step of the project, using national databases to estimate the availability of wind, solar and hydro resources. During the first visit some potential deployment locations were identified including the two rivers surrounding the village. Also, a meeting was held with the farmers to discuss biomass availability and interviews were done during the second visit to assess more accurately this resource.

3.5.1 Hydro resource

There are two rivers near Dewgain village. During the time of the first visit (done in March), there was almost no flow of water, so although not measured, the flow rate was near zero. In addition, the terrain is very flat, thus no significant heights were found. The second visit was at the start of the rainy season (end of June), and some days it rained but slightly. After the rain, the flow rate of the rivers was higher than during the first visit, but far from making an hydro plant feasible. Considering the situation found, hydro potential is not very promising here. Figure 3.17 shows the rainfall rates registered in a meteorological station situated 12 km away from the village [25].

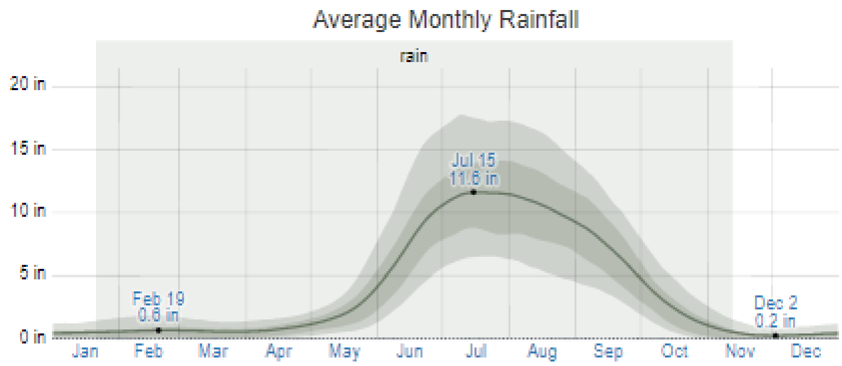

FIGURE 3.17: The average rainfall (solid line) accumulated over the course of a sliding 31-day period centred on the day in question, with 25th to 75th and 10th to 90th percentile bands. The thin dotted line is the corresponding average liquid-equivalent snowfall.

3.5.2 Wind resource

Although an unreliable assessment, initially villagers were asked about their knowledge of wind resources. During both visits we experienced only few episodes of wind, most during sunset. North of the village there are some stone hills, but they are covered with trees and other vegetation. Villagers indicated that only the first Monsoon month is consistently windy. There are some locations free of vegetation not being used by farmers, however the wind resource did not appear to be very promising either, as later assessment of available global databases confirmed these observations. Although wind resource is very dependant on the terrain conditions,

Figure 3.18 shows the wind speeds registered in a meteorological station situated 12 km away from the village, and has been considered as the reference values for the wind resource.

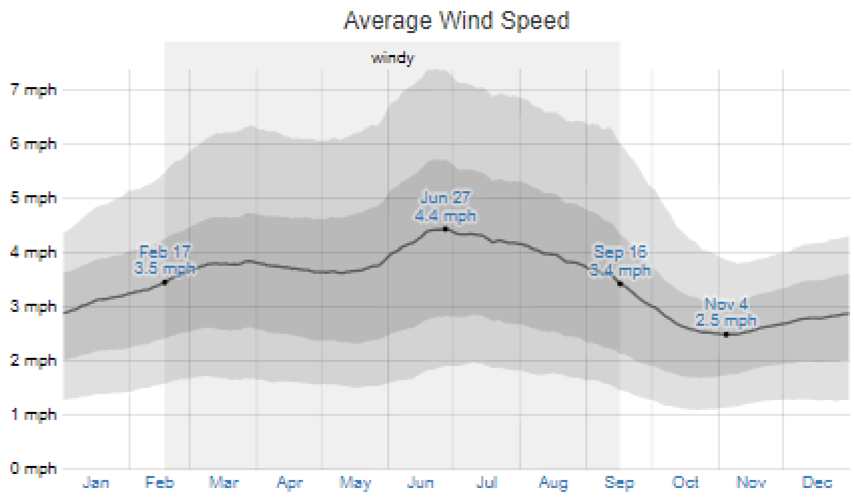

FIGURE 3.18: The average of mean hourly wind speeds (dark gray line), with 25th to 75th and 10th to 90th percentile bands.

3.5.3 Solar resource

The climate seems suitable for solar. During the first visit every day had a lot of solar irradiation, most of it during afternoon hours. Potential deployment areas were identified. Although the majority of household roofs are made of wood and tiles making them infeasible for holding solar panels, there are some concrete roofs. The larger ones are on the government primary school and the health center, and a few on households.

A total area of 450 m^2 of roofs free of shade and 320 m^2 with some tree shades were identified.

Additionally, some zones free of vegetation and not in use were identified. These areas have different owners; some are government others private property. The following map in Figure 3.19 shows the most promising zones (orange color), relatively near the main cluster.

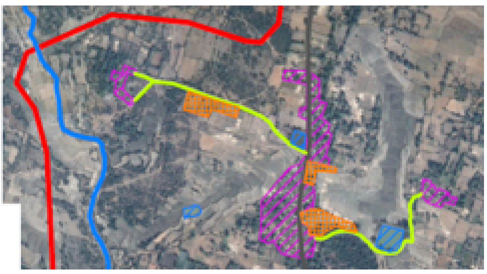

FIGURE 3.19: In orange, the locations free of vegetation and not in use near the village.

Some users are already using solar power, and one house has even installed a small solar photovoltaic (PV) panel and a 12 V battery. The family reported using it with much success during the load shedding hours. Also, five families are using solar rechargeable lamps, thus reducing kerosene consumption.

Regarding the availability of the solar resource, the NASA Surface Solar Energy Data Set [26], was consulted. The average monthly radiation values registered in the nearest point from Dewgain during the last 22 years are shown in Table 3.11.

TABLE 3.11: Average daily radiation

Month	Daily Radiation ($kW\,h/(m^2\,d)$)	Month	Daily Radiation ($kW\,h/(m^2\,d)$)
January	4.30	July	4.12
February	5.05	August	3.98
March	5.65	September	4.06
April	6.19	October	4.56
May	6.14	November	4.34
June	4.84	December	4.13

Also related with the solar resource, for PV generation dimensioning the hours of sunlight and the night hours are important. In Chapter 4 the component dimensioning is discussed, and the importance of this information is explained. Figure 3.20 shows the different sunlight hours through the year, while Figure 3.21 presents the amount of energy needed on an average day each month categorized by the time of the day it is required.

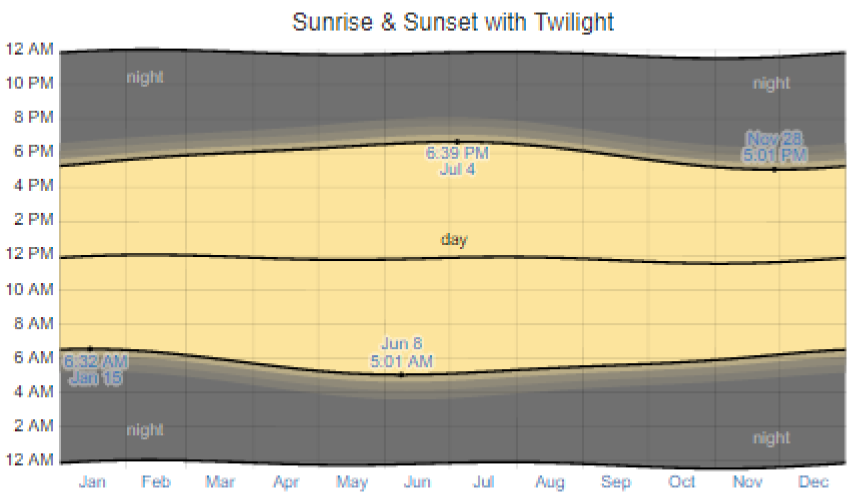

FIGURE 3.20: The solar day over the course of the year 2017. From bottom to top, the black lines are the previous solar midnight, sunrise, solar noon, sunset, and the next solar midnight. The day, twilights (civil, nautical, and astronomical), and night are indicated by the color bands from yellow to gray.

Finally, a neighbouring village (15 km away from Dewgain) has implemented a solar government scheme by which they have installed a solar street-light, solar panels on a social center roof, and some solar water pumps for household use. Regarding government schemes, during the second visit a meeting with Jharkhand Renewable

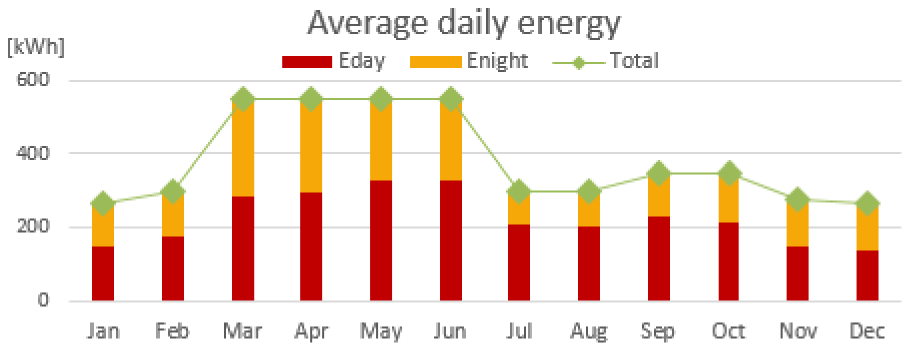

FIGURE 3.21: The energy needed on an average month day, categorized by the presence or absence of sunlight.

Energy Development Agency (JREDA) Project director was held. He informed about a solar photovoltaic rooftop scheme that covers up to 50% of the installation costs. The scheme has been recently implemented in the state. JREDA website has published a list of private companies with permission to implement such projects [27].

Thus, for the implementation phase, if access to the scheme is wanted, close collaboration with some of these companies is recommended. Although photovoltaic rooftop is the main PV systems affected by the scheme, the JREDA's project director encouraged us to apply to the subsidies even if the project isn't rooftop solar, because this is a non-exclusive condition.

As the solar resource analysis has shown, solar resource stands out as one of the more promising energy sources of the region.

3.5.4 Biomass resource

During the first visit, all the farmer families interviewed said that their main crop during the year was rice. Therefore, a meeting with the farmers was held in order to estimate their rice husk production, and their willingness to contribute some of this for a potential biomass project. Most of the farming land is dedicated to rice crops. Farmers informed us that the rice waste is used as feed for livestock, complementing the animal diet of eating other grasses and vegetables. However, the recent introduction of machine harvesting breaks the rice waste into an oily residue that animals do not eat. Also, when farmers bring their rice to the mills for processing, the mill owners sell the residue of husks to the paper industry.

The farmers produce an average of 10 quintals (1,000 kg) of rice per crop based upon one crop per year. With 146 farmer families, the community is producing approximately 146,000 kg of rice. Studies show that rice husk equals 20% of the weight of paddy production [28]. This suggests that more than 29,000 kg of rice husk is produced by the village farmers. Actual gasifier technologies use 1.6-1.8 kg of rice husk for producing 1 kW h, so more than 16,000 kW h could be potentially generated in a year from village rice husk. The potential for a biomass is therefore feasible, but even more so if the rice husk produced in the nearby industrial rice mills is considered.

During the second visit to Dewgain, one of these rice mills was visited. The rice mill is connected by the main road to the village, around 20 km away. They are processing rice through all the year, but due to the seasonality of the crop and the rice husk demand, the price they are selling the husk varies between 0.8-5 Rs./kg. The quantity available is very high, although they are using around 10% in a combustion chamber to generate steam, which they use for processing the rice. Their interest in the gasification project is high, because they are thinking about installing their own gasifier to produce electricity. So maybe some price arrangement for the rice husk purchase could be achieved.

Also during the second visit, the families were specifically asked about when they were harvesting the rice. Figure 3.22 shows the estimation of daily rice husk generation, based on the farmers answers and considering that 75% of the families are willing to contribute. The high number of families contributing is consequence of the enthusiasm they showed during the farmers meeting. To encourage the willingness of the community to participate, lessons learnt from other biomass projects recommend to purchase the biomass even at a symbolic price [29]. Thus, 1 Rs./kg will be considered as the purchase price from the community-produced biomass.

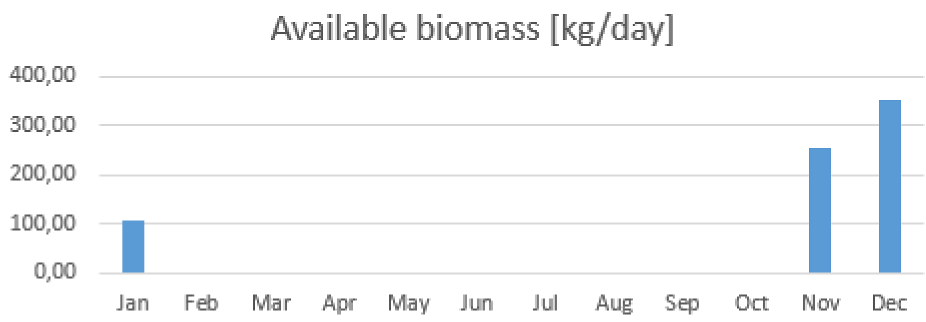

FIGURE 3.22: The rice husk produced by the community on an average day each month.

As the biomass resource analysis has shown, biomass will also be considered as a possibility for electricity generation.

Chapter 4

Solution Design

Based on the characteristics of the community studied and the potential of the resources in the area, this chapter presents the functionalities required from the system as well as the system architecture and the methods for dimensioning the different components.

4.1 System functionalities

From the previous chapter, solar and biomass have been identified as the renewable resources in the village region with more generation potential. Renewable generation has been defined as a compulsory condition for the project, so the options left for the generation of electricity are 100% solar, 100% biomass or a combination between both. As the main goal of the project is to provide a reliable and affordable electricity source, PV technologies will be considered for the solar resource, while rice husk gasification will be considered for the biomass resource.

Due to the geographic characteristics of the community settlement, the main cluster represents more than 83% of the households. So the majority of houses are located in a relatively small area, while the other clusters are less than 1 km away. Also, Dewgain families have been connected 3 years to the electrical grid, thus they already have some electrical appliances that represent a relatively high electricity consumption. This fact, added to the community size (194 families), makes an alternating current (AC) system the most feasible solution, as the cost effective limit for a direct current (DC) system of this characteristics has been established at 16 houses [30].

With all this considerations in mind, a *Central System Architecture* has been considered as the most viable option.

4.1.1 Model overview

PV generation and rice husk gasification generation provide electricity in DC and AC form respectively. On the other hand, the village is already connected to the grid, so all the loads work with AC electricity. Hence, a dual-bus system designed to provide 24 h AC electricity is needed. To achieve this level of service without an extremely costly amount of battery capacity, a fuel powered electricity generator, such as a diesel generator set or a fuel cell, is needed [31]. Such systems are usually referred to as hybrid. Figure 4.1 shows the different functions that the system has to provide, but replacing the diesel generator set for a biomass rice husk gasifier.

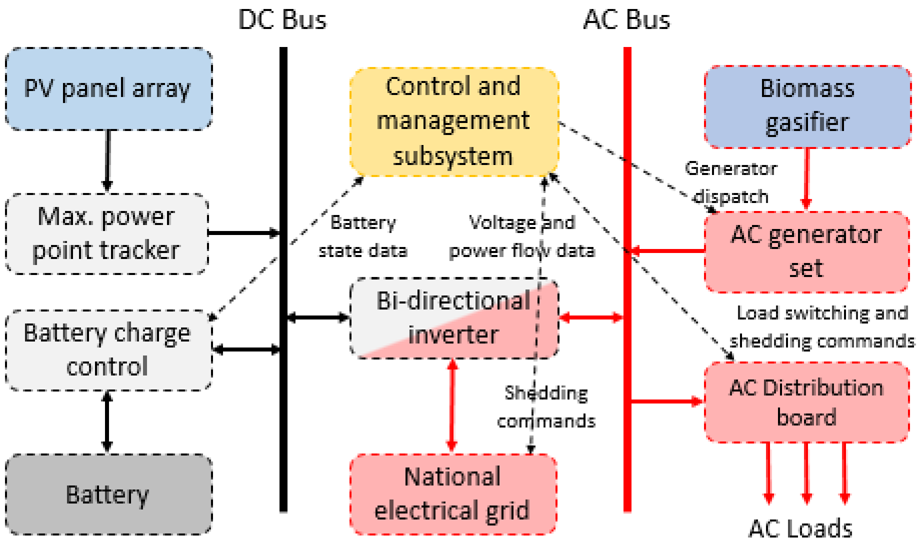

FIGURE 4.1: Central architecture for a dual bus hybrid system.

4.1.2 Specific functionalities

The following list presents the different functionalities of the system:

- The bidirectional inverter is able to convert DC from the PV panels and/or battery to AC to supply the loads and can also accept any surplus AC generator capacity to recharge the battery. Additionally, is the element connected to the grid, and can determine whether to supply electricity from the grid or to supply surplus electricity from the system to the grid.
- The control subsystem ensures the generator is dispatched whenever it predicts that the battery charge will not sustain the service until PV production resumes, or when PV production is inadequate. These dispatch decisions must take account of the need to operate the generator over a sufficient period and with a sufficient load so that its reliability is not compromised. The replacement of the diesel generator by a rice husk gasifier will increase the response time of the system, since the actual gasifier technologies need at least 5 min to start producing electricity. The control system will have to consider this increased response time in order to keep the electricity supply.
- The battery charge control provides the battery charging strategy to maximize the battery life, based on the technology selected for the batteries. Additionally, is protecting the batteries from potential overcharging or over-discharging damages.
- The maximum power point tracker (MPPT) is optimizing the power output from the solar panels, adapting the electrical conditions the panels are facing with the ever-changing meteorological conditions.
- The AC distribution board is able to protect the AC loads from possible grid failures. Additionally will include consumption meters, for the energy costs calculation.

- The AC generator set provides the additional electricity when the PV system, the batteries or the electrical grid are not able to meet the demand.
- The PV panel array is generating electricity through the solar irradiation.
- The biomass gasifier is generating producer gas through the gasification of the rice husk. This producer gas will be used by the AC generator set to produce AC electricity.
- The battery will store energy and stabilize the system from the changing electricity demand. The battery can be charged from the PV panel array, the grid or the AC generator set.

4.2 System architecture

The system architecture defines which elements will be in charge of the functionalities listed in the previous section. The actual state of technologies offers different possibilities for the system configuration. Figure 4.2 presents the combination of elements that have been considered for the design of the solution.

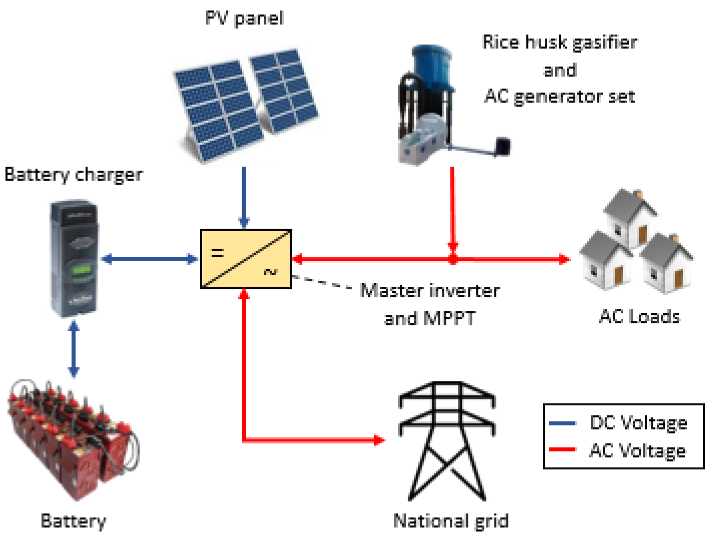

FIGURE 4.2: AC coupled hybrid system.

4.2.1 Elements and connections

The AC coupled system under consideration contains the following elements and connections:

- A bidirectional inverter that includes MPPT function. This is the central element of the system. The market offers different configurations, combining inverter, MPPT and battery charger functions. For this study inverters including MPPT function have been considered.
- PV panel arrays, connected unidirectionally with the DC side of the bidirectional inverter at the input ports of the MPPT. The section PV panel arrays -

bidirectional inverter has to be unidirectional, since the power will flow only from the PV panel arrays to the inverter when the PV panels generate electricity.

- A battery charger, connected bidirectionally with the DC side of the bidirectional inverter. The battery charger has to be programmed for the specific technology of the batteries, since this will change the charging patterns and the protection levels and will maximize the batteries life.
- A battery bank, connected bidirectionally with the battery charger. The section battery bank - battery charger - bidirectional inverter has to be bidirectional, since the power will flow from the inverter to the batteries for charging them, and from the batteries to the inverter for attending the demand.
- A rice husk gasifier that includes an AC generator set. This combination is already available in the market, with the advantage of matching dimensions of the AC generator set and the rice husk gasifier. If the selection of both elements is independent, there is the risk of over-dimensioning one of them. The AC generator set output is connected unidirectionally to the AC bus, since the power flow only from the AC generator to the AC bus when the producer gas generated in the rice husk gasifier is used in the AC generator.
- The AC loads. This element represents the final usage of the electricity. The connection of the users to the grid should include electrical protections and a metering device, in order to set the price to pay for the service. These connections can also include a consumption limiting system for protecting the micro-grid. These protections should be based on total power connected or total energy consumed in a period of time, and when the fixed level has been surpassed an automatic switch should disconnect that consumption point. Since the generation of the electricity has been defined as centralised, the connection of the AC loads to the AC bus has to be unidirectional.
- The AC bus is the element connecting the AC side of the bidirectional inverter to the AC generator set and the AC loads. Since the power will flow from the bidirectional inverter to the AC loads when there is a demand to attend, or from the AC generator set to the bidirectional inverter when batteries have to be charged, the AC bus has to be bidirectional.
- The national grid. The field study has demonstrated that the national grid is not properly supplying electricity to Dewgain. Despite this fact, the national grid is expected to work in the future, thus making the connection of the micro-grid to the national grid the optimal choice. The bidirectional inverter is the element connecting the micro-grid to the national grid. The national grid is connected with the AC side of the bidirectional inverter. Since the power will flow from the national grid to the AC loads or the batteries when the demand cannot be met by the micro-grid, and could flow from the micro-grid to the national grid when the system has an excess of energy, the connection has to be bidirectional.

4.3 Component dimensioning

This section presents the mathematical equations that have been used for dimensioning the different components of the system. The equations for the batteries, the inverter and the PV panels dimensioning have been obtained from "Mini-Grids for Rural Electrification of Developing Countries" [32], while the dimensioning of the battery charger equations have been obtained from "Blue Sky Energy's Technical Bulletin 100214" [33] and the dimensioning of the rice husk gasifier and AC generator set from a technology provider .

4.3.1 Battery

The capacity of the battery depends upon three things: (a) daily energy requirement (E, W h); (b) days of autonomy (A) (i.e. number of days for which storage is required) and (c) maximum allowable Depth of Discharge (T) of the battery (minimum percentage of the battery charge allowed before recharging it).

For a system that can segregate between the daytime energy requirement and the night-time energy requirement the capacity of the battery will be lower (than for a system that cannot segregate) the more daytime energy is required. This is because for a daytime load there is no need of storing a large proportion of solar generated DC electricity in battery. Rather, the DC electricity can be directly converted to AC electricity through the inverter. However, the battery capacity should be such designed, that it can take care of the sudden fluctuation in the solar radiation (such as swift movement of clouds would result in a sudden drop of solar irradiation). So, on an average, 5–8% of the daytime energy requirement can be added to the nocturnal energy requirement to find out the ideal *daily energy requirement*, which is used to design the battery capacity. E daily energy requirement for battery sizing in (W h) can be calculated as per the formula given in Equation 4.1.

$$E = E_{night} + 0.08 \cdot E_{day} \tag{4.1}$$

where,

E	Daily energy requirement for battery sizing (W h)
E_{night}	Nocturnal energy requirement (W h)
E_{day}	Day-time energy requirement (W h)

Secondly, for determining the number of days of autonomy, the advantage of installing a hybrid system is that solar PV array is sized in such a way that it can cater to the required energy in most of the months in a year and in the remaining month battery can be charged through the biomass generator and thus there is no extra day (or maximum one day) for storing energy in battery. For a 100% PV solution, at least 2 days of battery autonomy have to be considered. For the dimensioning of the battery in this study, it has been considered that the higher percentage of biomass generation used, the lower autonomy is needed from the batteries, ranging from 2 days to 1 day. Therefore, A days of autonomy can be calculated as per formula given in Equation 4.2.

$$A = 2 - \frac{E_{BM}}{ADL} \tag{4.2}$$

where,

A	Days of autonomy (d)
E_{BM}	Daily energy requirement for BM plant sizing (W h)
ADL	Average daily load (W h)

Finally, Q_{batt} capacity of the battery required in (A h) is calculated as per formula given in Equation 4.3.

$$Q_{batt} = \frac{E \cdot A}{V \cdot DoD \cdot \eta_{inv} \cdot \eta_{cable}} \tag{4.3}$$

where,

Q_{batt}	Capacity of the battery required (A h)
E	Daily energy requirement for battery sizing (W h)
A	Days of autonomy (d)
V	System voltage (V)
DoD	Maximum allowance depth of discharge
η_{inv}	Inverter efficiency
η_{cable}	Efficiency of the cables delivering the power from the battery to the load

The system voltage is the DC voltage level of the battery side and the maximum allowable depth of discharge of the battery depends upon the type as well as characteristic of the battery.

4.3.2 PV panel array

The sizing of the solar PV array can be achieved by estimating and adding the solar PV array sizing for supplying the daily energy required for the battery and the solar PV array sizing based on daily daytime energy required. Solar PV array capacity for supplying the daily daytime energy required can be obtained as per formula given in Equation 4.4.

$$W_{PV,daytime} = \frac{E_{day}}{ESSH \cdot \eta_{sys,daytime}} \tag{4.4}$$

where,

$W_{PV,daytime}$	Peak wattage of the array for supplying the daytime energy (W)
E_{day}	Daily daytime energy requirement (W h)
$ESSH$	Equivalent Hours of Sunshine (h)
$\eta_{sys,daytime}$	Daytime system efficiency ($\approx 80\%$)

Solar PV array capacity for supplying the daily energy required for the battery can be obtained as per formula given in Equation 4.5.

$$W_{PV,batt} = \frac{E}{ESSH \cdot \eta_{sys,overall}} \tag{4.5}$$

where,

$W_{PV,batt}$	Peak wattage of the array for supplying the batteries (W)
E	Daily energy requirement for battery sizing (W h)
$ESSH$	Equivalent Hours of Sunshine (h)
$\eta_{sys,overall}$	Total system efficiency ($\approx 65\%$)

It can be observed how the efficiency used for the daytime energy calculation is higher than the efficiency for the battery energy. That is because the energy flow for the daytime loads goes from the PV panel array to the inverter and from there to the AC loads, so there is no power loss for storing the energy in the batteries.

Finally, W_{PV} total solar PV capacity requirement in (W) is calculated as per formula given in Equation 4.6.

$$W_{PV} = W_{PV,batt} + W_{PV,daytime} \tag{4.6}$$

where,

W_{PV}	Peak wattage of the solar PV array (W)
$W_{PV,batt}$	Peak wattage of the array for supplying the batteries (W)
$W_{PV,daytime}$	Peak wattage of the array for supplying the daytime energy (W)

4.3.3 Battery charger

The sizing of the battery charger is based on the electrical limitations of this component. Two electrical limitations must be respected. The maximum charger open circuit voltage and the maximum output charger power can't be surpassed.

In a conventional design, maximum charger open circuit voltage is defined by the number of PV panels connected in series to the same battery charger and the open circuit voltage of each of the panels connected. But in the centralised architecture presented the battery charger is not directly connected to the PV panels, so the voltage level will be fixed by the bidirectional inverter, assuring the limit is not surpassed.

Maximum output charger power is defined by the total power that the inverter will direct to the batteries. As the system is more likely to charge the batteries from the PV panels (and charges from the biomass gasifier or the national grid shouldn't be usual), the maximum output charger power will depend on the amount of power from the PV panels redirected to the batteries. The number of battery chargers with a specific maximum output charger power can be obtained as per formula given in Equation 4.7.

$$N_{charger} \geq \frac{W_{PV,batt}}{P_{max,charger}} \tag{4.7}$$

where,

$N_{charger}$	Number of chargers required
$W_{PV,batt}$	Peak wattage of the array for supplying the batteries (W)
$P_{max,charger}$	Maximum output charger power (W)

4.3.4 Bidirectional inverter and MPPT

The selection of the inverter in a centralised electrification design is one of the key aspects. The goal of this thesis is not to obtain a detailed list of the components needed for the electrification of Dewgain, but to design a dimensioning process of the generation sources that can provide a realistic estimation of the project costs. For selecting an inverter there are lots of electrical limits that have to be observed, as well as other considerations such as the communications modules used for controlling the system. For simplification of the process at this early stage of the electrification project, only the capacity or rating of the inverter has been considered as the defining characteristic. The capacity or rating of the inverter required can be obtained as per formula given in Equation 4.8.

$$P_{AC,rated} \geq Total\ supplied\ AC\ wattage \tag{4.8}$$

where,

$P_{AC,rated}$	Rated AC power of the inverter (W)
Total supplied AC wattage	Peak wattage of the daily load curve (W)

The model has to consider that not all the AC load will be supplied from the inverter. In fact, the rice husk gasifier will be directly supplying part of this load. For the dimensioning of the inverter some levels of AC load have been considered, depending on the amount of energy supplied by the biomass plant. The higher amount of energy supplied by the biomass plant, the lower peak wattage of the daily load curve that has been considered for the inverter.

The MPPT function has also its own electrical limits. This can't be surpassed by the electrical characteristics of the PV panels connected to the MPPT. For simplification this limitations haven't been considered.

4.3.5 Rice husk gasifier and AC generator set

For the dimensioning of the gasifier, the total daily energy required to be produced by the AC generator set has been considered. The defining characteristic of a gasifier and AC generator set is the capacity, or the amount of power that the generation plant is capable to offer. Capacity of the biomass (BM) plant required can be obtained as per formula given in Equation 4.9.

$$W_{BM,r} = \frac{E_{BM}}{BM_{WH}} \tag{4.9}$$

where,

$W_{BM,r}$	Capacity of the BM plant required (W)
E_{BM}	Daily energy requirement for BM plant sizing (W h)
BM_{WH}	Daily working hours of the BM plant (h)

Additionally, the fuel consumed daily has a big impact on the operation costs of the system and can be obtained as per formula given in Equation 4.10.

$$FC_{day} = E_{BM} \cdot \frac{BM_C}{W_{BM}} \tag{4.10}$$

where,

FC_{day}	Daily fuel consumption (kg)
E_{BM}	Daily energy requirement for BM plant sizing (W h)
BM_C	Hourly maximum fuel consumption (kg/h)
W_{BM}	Capacity of the BM plant (W)

4.3.6 System considerations

The equations for dimensioning the different components of the system have been presented. Some of the parameters are fixed by the characteristics of the model chosen for each component, but others depend on the external conditions, like the amount of energy required or the equivalent hours of sunshine (found in Table 3.11). The system has to be able to cover the electric energy needs of the community through all the year, which is equivalent to the Equation 4.11. Thus, a 0 load shedding condition has been imposed.

$$Total\ load = E_{night,total} + E_{day,total} \tag{4.11}$$

where,
Total load Daily energy consumption (W h)
$E_{night,total}$ Total nocturnal energy requirement (W h)
$E_{day,total}$ Total daily daytime energy requirement (W h)

The values for *Total load*, $E_{night,total}$ and $E_{day,total}$ have been obtained from the field study and data analysis, and are presented in Table 4.1.

TABLE 4.1: Total load, day load and night load for each month

Time period	**Total load (kWh)**	**Total daily load (kWh)**	**Total nocturnal load (kWh)**
January	264.22	146.15	118.08
February	300.22	176.99	123.23
March	549.62	285.86	263.77
April	549.62	297.52	252.11
May	549.62	330.19	219.43
June	549.62	330.19	219.43
July	300.22	210.84	89.38
August	300.22	205.73	94.49
September	345.22	229.27	115.96
October	345.22	214.38	130.84
November	277.72	151.26	126.47
December	264.22	139.55	124.67

Relating the total load with the generation of the rice husk gasifier and the PV panel array, the Equation 4.11 can be rewritten as Equation 4.12.

$$Total\ load = E_{BM} + E_{night} + E_{day} \tag{4.12}$$

where,
Total load Daily energy consumption (W h)
E_{BM} Daily energy requirement for BM plant sizing (W h)
E_{night} Nocturnal energy requirement for PV array sizing (W h)
E_{day} Daily daytime energy requirement for PV array sizing (W h)

The dimensioning strategy consists in calculate all the combinations between 100% PV generation - 0% BM generation and 0% PV generation - 100% BM generation, and selecting the best combination. For the BM generation, the generation strategy chosen has been to minimize the load peak required for the inverter, thus minimizing the inverter size. In order to do that, the BM plant has to generate at least during the load peak hours. This occurs during mornings, so for low BM generation percentages the energy generated by the BM plant reduces the value of E_{day}. This condition has been implemented in the model by Equation 4.13. For higher BM percentages, the generation covers all the daytime energy and starts reducing the value of E_{night}. This condition has been implemented in the model by Equation 4.14.

$$\begin{cases} E_{day} = E_{day,total} - E_{BM} & ; E_{BM} \leq E_{day,total} \\ E_{day} = 0 & ; E_{BM} > E_{day,total} \end{cases} \tag{4.13}$$

$$\begin{cases} E_{night} = E_{night,total} & ; E_{BM} \leq E_{day,total} \\ E_{night} = E_{night,total} + E_{day,total} - E_{BM} & ; E_{BM} > E_{day,total} \end{cases} \tag{4.14}$$

The system has been simulated for all the months, changing the day and night loads and solar radiation since they depend on the month. Each simulation has been done with a 0.04% percentage step between PV generation and BM generation, meaning that for example first simulation for January has 100% PV generation and 0% BM generation, second simulation for January has 99.96% PV generation and 0.04% BM generation and so on.

The selection of each component for each simulation has been done based on overall cost optimization, as Chapter 5 exposes.

Chapter 5

Optimisation Process

The optimization process consists in simulating all the possible generation combinations between PV and BM technologies. For each combination, the components assuring a minimum overall project costs are selected. This is done for all the months, providing a project optimal cost for every month (the combination providing a minimum cost for that month). The month with the higher costs is considered as the worst-case month, and the system is finally dimensioned considering it as the base case.

5.1 Objective function

The objective function specifies the aspect of the solution that has to be optimized. For this project, the overall cost of the project is considered. These cost includes the initial cost of installation of the equipment and the costs that are expected through all the project life. Operation and maintenance (OM) costs and fuel costs are considered to be paid every year, while replacement costs of some components occur more spread over time. The objective function can be calculated as per formula given in Equation 5.1.

$$Z_i = MIN(NPC_1, ..., NPC_k) = MIN\left(\sum_{t=0}^{T} \frac{C_{t,j}}{(1+r)^t}\right) \tag{5.1}$$

where,

Z_i	Optimal overall project cost for the i combination of generating technologies (Rs.)
NPC_j	Net present cost for the j combination of components (Rs.)
$C_{t,j}$	Expected cost during the period t for the j combination of components (Rs.)
r	Annual interest rate
t	Year considered
T	Project life total number of time periods (years)

Z_{month} is defined as the set of minimum NPC for each combination of generating technologies. For example, if a percentage step between generating combinations of 0.04% is set, first simulation for January has 100% PV generation and 0% BM generation and the minimum overall project cost combination of components is calculated, second simulation for January has 99.96% PV generation and 0.04% BM generation and the minimum overall project cost combination of components is calculated and so on, until reaching the case 0% PV generation and 100% BM generation. This is done for all the months, changing the external conditions of the system (whole day loads, day and night loads and solar radiation). Finally the worst-case month is defined using Equation 5.2.

$$Z_{worst} = MAX(MIN(Z_{Jan}), MIN(Z_{Feb}), ..., MIN(Z_{Dec})) \tag{5.2}$$

where,

Z_{worst}	Optimal overall project cost for the worst month (Rs.)
Z_{Jan}	Set of minimum NPC for the January month (Rs.)
Z_{Feb}	Set of minimum NPC for the February month (Rs.)
Z_{Dec}	Set of minimum NPC for the December month (Rs.)

5.2 Component selection

The NPC that is calculated on every iteration of the optimisation algorithm depends on the characteristics of the components considered for the system. Each type of component has its own characteristic costs, as well as its particular dimensions. The calculation of the system needs for each type of component are translated in a total number of components of a specific model that are needed in the system, which then is translated into a cost. The algorithm chooses the component models of each category that minimize the overall project cost.

Some specific characteristics have to be observed during the component selection:

5.2.1 Battery

Batteries cost include the initial fixed cost of installation, the annual OM costs and the periodical replacement cost. The life of the batteries depends on the technology and model, and marks when they need to be replaced. Additionally the real batteries have a fixed capacity value and a voltage value. The required battery capacity and the system DC side voltage impose to the batteries the constraints found in Equation 5.3 and Equation 5.4.

$$N_{batt} \cdot Q_{batt,s} \geq Q_{batt} \tag{5.3}$$

where,

N_{batt}	Total number of batteries
$Q_{batt,s}$	Single battery capacity (A h)
Q_{batt}	Capacity of the battery required (A h)

$$\frac{N_{batt} \cdot V_{batt}}{n} = V \quad ; n \in \mathbb{N} \tag{5.4}$$

where,

N_{batt}	Total number of batteries
V_{batt}	Single battery voltage (V)
n	Number of battery branches
V	System voltage of the DC battery side

The number of batteries connected in series in a single branch has to reach the desired voltage level. Additionally the total amount of batteries connected have at least to fulfil the battery storage requirement.

Battery models

The batteries selected for the study are all lead-acid technology. This is currently the most extended technology, so prices are more competitive [30]. The different costs have been researched in catalogues, and some commercial providers are included. The models are presented in Table 5.1.

TABLE 5.1: Battery models considered for the study

$Q_{batt,s}$ (A h)	V_{batt} (V)	**Fixed cost (Rs./u)**	**O&M (Rs./u/year)**	**Replacement period (years)**	**Provider**
25	12	2600.00	325.00	6	Amstron, CSB, Power-Sonic
50	12	4875.00	325.00	6	Amstron, CSB, Power-Sonic
100	12	9750.00	325.00	6	Amstron, CSB, Power-Sonic
1156	6	91000.00	650.00	9	Rolls

5.2.2 PV panel array and battery charger

PV panel array costs include the initial fixed cost of installation and the annual OM costs. The costs for the battery charger include only the initial fixed costs of installation. Replacement costs are not considered since the project life is expected to be shorter than the PV panels and battery chargers life. Both elements are considered simultaneously in terms of costs, since the PV array total size is the magnitude that dimensions the battery charger. The real PV panels have a fixed capacity value, as the real battery chargers have. This fact imposes to the PV panels and the battery chargers the constraints found in Equation 5.5 and Equation 5.6.

$$N_{PV} \cdot W_{pv} \geq W_{PV} \tag{5.5}$$

where,
N_{PV} Total number of PV panels
W_{pv} Single panel power peak (W)
W_{PV} Required power peak of the solar PV array (W)

$$N_{charger} \geq \frac{W_{PV,batt}}{P_{max,charger}} \tag{5.6}$$

where,
$N_{charger}$ Number of chargers required
$W_{PV,batt}$ Peak wattage of the array for supplying the batteries (W)
$P_{max,charger}$ Maximum output charger power (W)

PV panel array and battery charger models

The fixed costs for the PV panels have been taken from actual catalogues, while the OM costs considered come from [23]. For the battery charger models the fixed costs have been obtained from catalogues. Some commercial providers are included. The models are presented in Table 5.2 and Table 5.3.

TABLE 5.2: PV panels models considered for the study

Model	W_{pv} (W)	Fixed cost (Rs./u)	O&M (Rs./W/year)	Provider
C6SU-P	330	9653.00	1.19145	Canadian Solar
Duo Max	270	7371.00	1.19145	Trina Solar

TABLE 5.3: Battery charger models considered for the study

Model	$P_{max,charger}$ (W)	Fixed cost (Rs./u)	Provider
Conext MPPT 80 600	4800	87750.00	Schneider Electric
Conext MPPT 60 150	3500	39000.00	Schneider Electric
FM80-150 VCC	4000	34450.00	Outback Power
FM60-150 VCC	3000	30225.00	Outback Power

5.2.3 Inverter

Inverter costs include the fixed installation costs and the annual OM costs. Replacement costs are not considered since the project life is expected to be shorter than the inverter life. The inverter selection is based on the dimensioning process exposed in the previous chapter, and doesn't require any additional constraint equation. On the other hand, the selection of the inverter model fixes an efficiency value that is used for dimensioning the battery capacity storage requirement. As a general rule of thumb, the efficiency is better for larger rated AC power inverters.

Inverter models

The models selected include the MPPT function. The fixed costs for the inverters have been taken from actual catalogues, while the OM costs considered come from [23]. Some commercial providers are included. The models are presented in Table 5.4.

5.2.4 Rice husk gasifier

Rice husk gasifier cost include the initial fixed cost of installation, the annual OM costs, the annual replacement costs of some components and the annual fuel costs. The real gasifiers have a maximum capacity, that fixes the constraint presented in Equation 5.7.

TABLE 5.4: Inverter models considered for the study

$P_{AC,rated}$ (kW)	η_{inv}	**Fixed cost (Rs./u)**	**O&M (Rs./year)**	**Provider**
10	96%	134550.00	3250.00	ABB
15	96%	171685.00	3250.00	Zeversolar
20	97%	180133.00	3250.00	Zeversolar
33	97%	173745.00	3250.00	Zeversolar
50	98%	243750.00	3250.00	ABB
55	98%	268125.00	3250.00	ABB, SMA
60	98%	292500.00	3250.00	SMA
70	98%	341250.00	3250.00	ABB, SMA
80	98%	390000.00	3250.00	ABB, SMA
90	98%	438750.00	3250.00	ABB, SMA
100	98%	487500.00	3250.00	ABB, SMA
110	98%	536250.00	3250.00	ABB, SMA

$$N_G \cdot W_g \geq W_{BM,r} \tag{5.7}$$

where,

N_G	Total number of rice husk gasifiers
W_g	Single gasifier capacity (W)
$W_{BM,r}$	Required capacity of the BM plant (W)

Rice husk gasifier models

The rice husk gasifier fixed costs, OM costs, fuel consumptions and replacement costs have been directly obtained from an Indian manufacturer. Thus, the name of the company and the different models is protected by a disclosure agreement. Despite this fact, the different values used for the simulations are presented in Table 5.5.

TABLE 5.5: Rice husk gasifier models considered for the study

W_g **(kWe)**	**Fixed cost (Rs./u)**	**O&M (Rs./kWh)**	**Replacement cost (Rs./kW·year)**	**Peak consumption (kg/h)**
20	1675600.00	0.50	48000.00	48
30	2212500.00	0.50	72000.00	72
40	4696400.00	0.50	96000.00	96
50	7858800.00	0.50	120000.00	120
70	9823500.00	0.50	168000.00	180
100	11593500.00	0.50	240000.00	240

5.3 System parameters

Finally, there are some parameters from the system that are still undefined. Table 5.6 presents the rest of the system data.

TABLE 5.6: System data

V: DC Voltage on battery side (V)	48
r: Annual interest rate (%)	4
T: System lifespan (years)	20
Batteries	
DoD: Maximum allowance depth of discharge (%)	50
η_{cable}: Efficiency of the cables (%)	95
$\eta_{sys,overall}$: Total system efficiency (%)	65
$\eta_{sys,daytime}$: Daytime system efficiency (%)	80
Biomass	
Local rice husk price (Rs./kg)	1
Rice mill rice husk price (Rs./kg)	3
Local available rice husk (kg/year)	21900

Chapter 6

Results Validation

6.1 Initial results

The system is simulated with the parameters exposed in the previous chapters. For simplicity in this initial analysis, each month is considered independently, as if the whole year behaviour had the conditions of the simulated month. For each month, the optimal components selection is found for each PV - BM generation proportion. The proportion step between each simulation is set to 0.04%, meaning that for the first simulation the generation proportion is 100% PV - 0% BM, for the second simulation the generation proportion is 99.96% PV - 0.04% BM and so on. In total, a set of 2501 combinations of generation proportions is obtained for each month.

The optimised overall project costs for each generation combination and each month are presented in the Appendix E. The differences between months with the same load profiles are minimum, only caused by the differences between solar radiation values. The summer months (March to June) are clearly the costliest. The generation proportions with minimum costs for each month are presented in Table 6.1.

TABLE 6.1: Minimum costs combination for each month

Month	PV generation	BM generation	Overall project costs (Rs.)
January	0%	100%	8216048.72
February	100%	0%	8775816.79
March	100%	0%	13778210.72
April	100%	0%	13061090.39
May	100%	0%	13005982.31
June	100%	0%	**14909148.32**
July	0%	100%	8976639.69
August	0%	100%	8976639.69
September	100%	0%	10762750.48
October	100%	0%	10114530.15
November	0%	100%	8501270.33
December	0%	100%	8216048.72

The worst month, from the generation dimensioning point of view, is June. In terms of load peak, the month that requires the biggest inverter is September. It is clear that the algorithm is choosing extreme solutions when all the year is considered to have the same load and solar radiation conditions. Hybrid solutions seem to be economically suboptimal, and either a 100% PV system or 100% BM system appear as the optimal solutions depending on the solar radiation and electrical load conditions combinations.

6.2 Worst-case optimisation

In reality, the system is not going to work in constant conditions through all the year. In fact, if the initial solution for the worst month is taken as valid, the rest of the year the system will be over-dimensioned. The advantage of an hybrid system (comprising PV and another controllable generation technology as BM gasifier), is that it combines the relatively lower overall costs of the PV system with the adaptability of the BM gasifier generation, allowing the PV system to be smaller and only using the BM gasifier during the months of higher electricity demand and/or low PV generation.

In this second phase of the optimisation, the optimal configurations obtained for the worst month are simulated with the rest of the months conditions. Thus, a more realistic approximation of the costs is obtained, since now the simulation is considering the year variation in the load and solar radiation conditions.

The algorithm calculates for each suboptimal combination previously found, how much energy is the PV system generating, and supplies the rest with the BM system. With the year need of BM generated energy, the total fuel consumption is obtained. The local availability of the BM is limited, so only the first 21,900 kg are charged at 1 Rs./kg. Any additional fuel required is charged at 3 Rs./kg. Since the suboptimal combinations are taken from the worst month, the system is always able to supply enough energy the rest of the months.

Finally, the algorithm considers the inverters used in September combinations, and substitutes the original inverters used in June for the bigger ones used in September. The overall project costs for each PV - BM generation combination are presented in Figure 6.1.

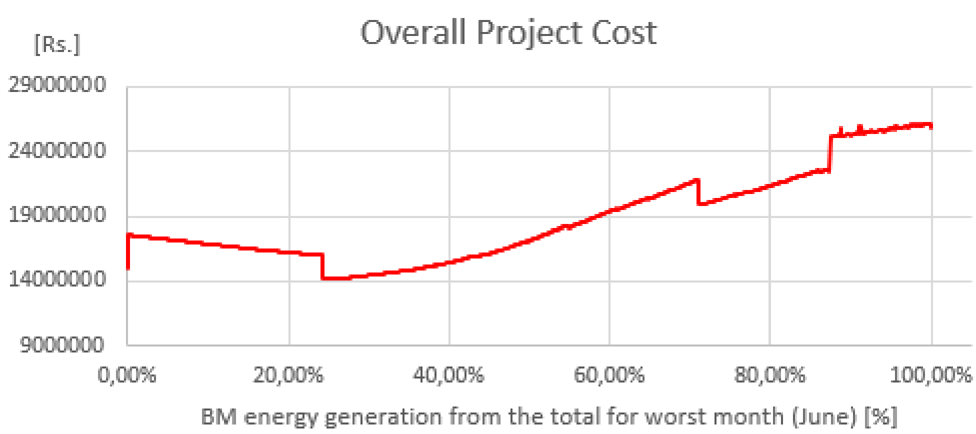

FIGURE 6.1: Overall costs of the project, considering all the year variations.

A comparison between the suboptimal solution obtained through the initial optimisation and the optimal solution obtained with this additional considerations is presented in Table 6.2.

TABLE 6.2: Optimal and suboptimal solutions comparison

Solution	PV generation	BM generation	Overall project costs (Rs.)
Optimal	73.96%	26.04%	14197003.41
Suboptimal	100%	0%	14909148.32

The improvement in the overall costs by using a hybrid system is a reduction of Rs. 712,144.91 (4.78% of the total costs).

6.3 System performance

As a validation of the results, the optimised system performance is presented. For each month, the energy generated by the PV system is calculated and compared with the estimated energy need. For the cases where this energy generated doesn't meet the month's energy need, the additional generation from BM system is calculated. Figure 6.2 presents the amount of energy generated by each generation technology for each month and Table 6.3 shows the amount of extra energy generated by the PV system that could be supplied to the national grid.

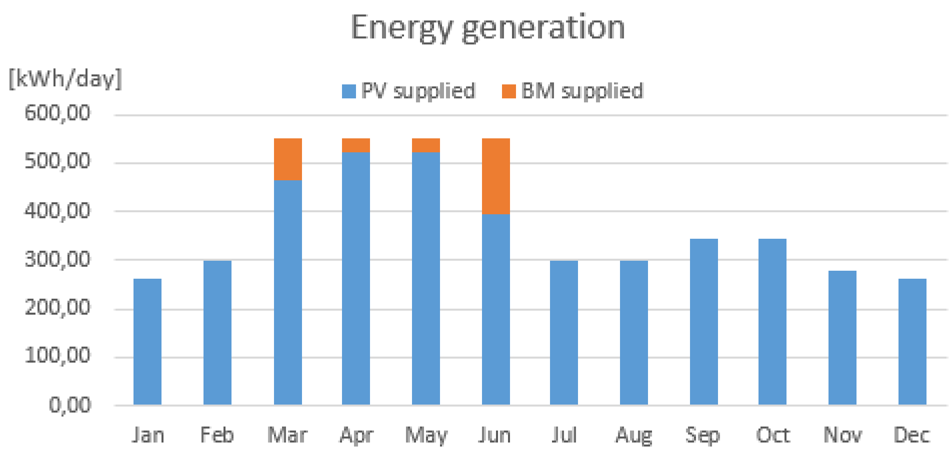

FIGURE 6.2: Energy generated by technology for each month.

Overall, the months with a surplus PV generation will provide to the national grid more than 19 GWh/year. The BM fuel consumption of the rice husk gasifier is approximately 21800 kg/year, very close to the 21900 kg locally generated. The limitation of cheap biomass fuel (locally available biomass) is influencing heavily the optimal solution. Any deal arranged with industrial rice mills to provide the system with rice husk at 1 Rs./kg or less should be considered, since it can potentially reduce the PV system size and the overall project costs. The monthly fuel consumption for the optimised system is shown in Figure 6.3.

TABLE 6.3: Energy generated by each technology and extra PV generated energy.

Month	**PV generation**	**BM generation**	**PV extra generation (kWh/day)**
January	100.00%	0.00%	116.74
February	100.00%	0.00%	150.23
March	84.83%	15.17%	0.00
April	94.77%	5.23%	0.00
May	94.66%	5.34%	0.00
June	71.42%	28.58%	0.00
July	100%	0%	63.30
August	100%	0%	48.87
September	100%	0%	4.46
October	100%	0%	51.63
November	100%	0%	104.74
December	100%	0%	99.16

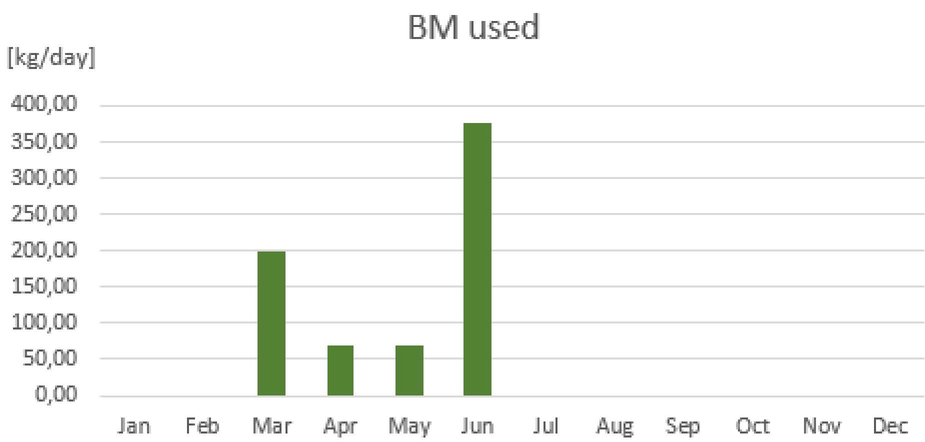

FIGURE 6.3: Monthly biomass usage.

6.4 Solution cost

Finally, a list of the components selection for the optimised solution is presented in Table 6.4. The different costs for each component are presented in Table 6.5, including the total costs for the whole project lifespan.

The total costs for the 20 years lifespan of the project add up to Rs. 14,197,003.41. A detailed cost overview for each component compared to the total project cost is presented in Figure 6.4. Finally, the costs are presented categorised by each component and each cost category, both in percentage and absolute values in Figure 6.5 and Figure 6.6.

TABLE 6.4: Final component selection.

Category	Model	Quantity
Battery	Rolls 1156 Ah	16
PV panel	Duo Max	455
Battery charger	FM80-150 VCC	19
Inverter	SMA 90 kW	1
BM gasifier	20 kWe	1

TABLE 6.5: Costs related to each component.

Category	Fixed cost (Rs.)	O&M cost (Rs./year)	Fuel cost (Rs./year)	Replacement cost (Rs./year
Battery	1456000.00	10400.00	0.00	161777.78
PV panel	3353805.00	146369.63	0.00	0.00
Battery charger	654550.00	0.00	0.00	0.00
Inverter	438750.00	3250.00	0.00	0.00
BM gasifier	1675600.00	4534.26	21764.47	48000.00
Total (20 years)	**7578705.00**	**3284475.10**	**434416.01**	**2899407.30**

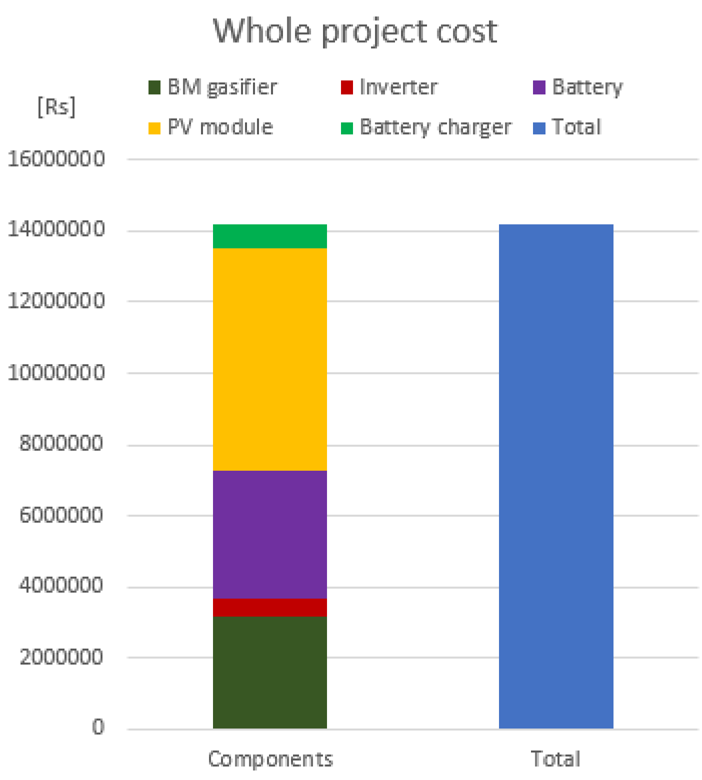

FIGURE 6.4: Whole project costs by component.

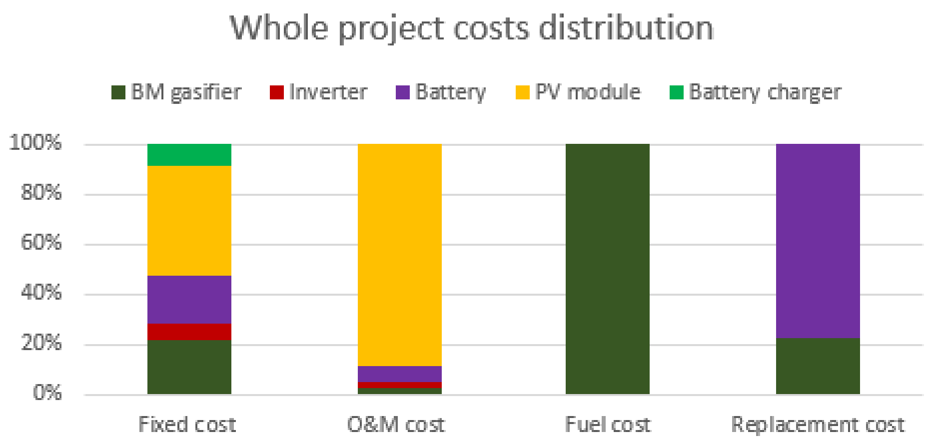

FIGURE 6.5: Percentage of whole project costs, by component and cost category.

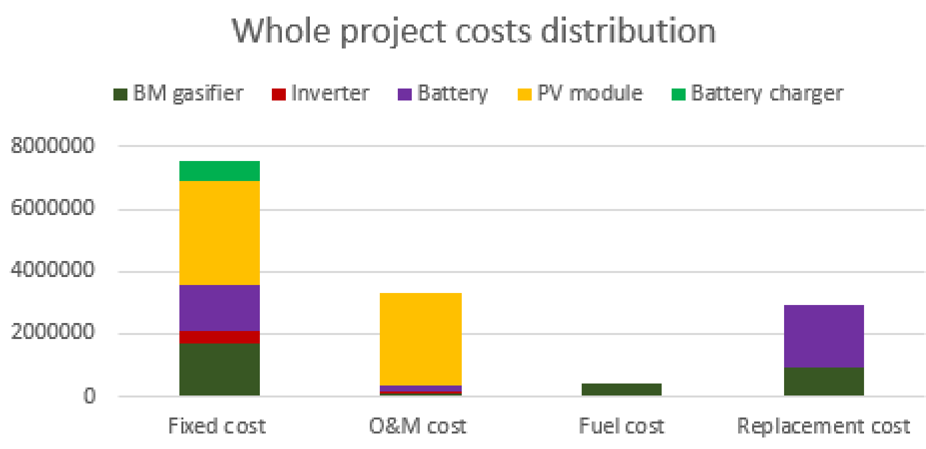

FIGURE 6.6: Overview of whole project costs, by component and cost category.

Chapter 7

Conclusions and future directions

7.1 Conclusions

This thesis has presented the work done during 6 months at Amrita Vishwa Vidyapeetham University, as an international exchange program. The four objectives defined at the start of the thesis have been vastly covered.

First of all, the methodology followed during the visits to Dewgain has been presented, with a special emphasis in the different aspects an energy assessment should cover for the study of a rural community. The first-hand practical experience presented exhaustively can be used as a guide for future assessments.

Second, the results obtained after the field work and subsequent data analysis have been presented in a descriptive way. The several efforts made by the whole team during the visits have provided the project with a solid basement to understand the actual situation of the community, therefore characterising the community needs in detail.

Third, a study of the actual rural electrification techniques and a extensive bibliography consultation has provided the insight to propose a design solution technically feasible. The identification of solar and biomass energy sources as the most promising for the project plus the physical characteristics and energetic needs of the community, has led to a centralized dual-bus mini-grid architecture as the solution proposal.

Fourth, an optimisation process for the dimensioning of the system has been presented. Although the process and the final solution are limited to the specific economics of the components under consideration, the early stage of the project when this process can be applied can help to estimate initial costs before the particular component selection phase. Thus, the economical viability of this projects can be considered at an earlier stage.

Finally, the process has been applied to optimise the solution for the studied community. The performance and lower costs of a hybrid PV - BM system has been validated, and the solution sets the starting point for specific component selection and a detailed implementation plan that can solve the electrification problem in Dewgain.

7.2 Future directions

As the thesis presented has been the first electrification project done in Dewgain by Live-in-Labs program, and there is the prevision to follow this work in order to implement a solution, I would like to use this final section of the thesis to point out which I think should be the future directions for the project.

- The most important of all, future electrification projects should maintain (if not enhance) the community participatory approach. The community will be the beneficiary of the project, as well as the final user, and even the operator (in case the system is run by themselves). It is key for the project success that future decisions related with the project are taken with the participation of the **whole** community. A good way to encourage the community participation could be to initiate an Electrification Committee, where the different village groups have representation. What will the most urgent things for the community to decide?
- Implement an energy efficiency program. The solution won't be effective if the community is not aware of the energy scarcity. They have to manage their electrical appliances in an efficient way. In addition, to change the incandescent bulbs for LED bulbs is mandatory in order to reduce the energy needs from the community, as Chapter 4 has demonstrated. Some subsidy program for obtaining new LED bulbs could be implemented, even the costs can be considered as part of the project costs. The Committee can help to implement this programs, as well as Amrita SERVE. If the programs are not implemented before the electrification is done, the project won't succeed.
- Define critical aspects of the system: who will be the owner, who will operate it, how will be the fees collected and which will be the different tariffs. Although PV system needs almost no maintenance, the biomass plant has to be operated by full-time workers. They can be members of the community and receive a salary, but the selection process should be very clear to avoid conflicts. All these aspects should be defined with the community, otherwise the project success can be seriously in danger. Additionally, the Committee can help in finding the suitable terrains to implement the system and negotiate with the actual land owners.
- Search financial funds. Jharkhand government is offering subsidies to PV projects, but the implement phase should be closely revised by authorised companies. Other funds can be requested to international agencies. All the funds found can help the community to pay a lower price for the system.
- Contact the telecommunications company that owns the Telecom tower, and offer them a electricity tariff to connect the tower to the grid instead of running the diesel generator.
- Select the final components of the system. This thesis has dimensioned the generation system to meet the energy needs. Other elements as the security components or metering devices that the system has to include haven't been considered, but should be carefully selected.

As the list shows, there are still lots of things to do and aspects to consider. I hope this thesis has helped in some way to set a solid basement for the electrification of Dewgain to become a reality.

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Appendix A

Social impact study check-list

Appendix A: Social impact study check-list

Here a check-list is presented, in order to facilitate the informal process of collecting information about the baseline situation:

Field	Topic	Parameters
Geography (the data can be completed with local maps)	Climate	Temperatures, rain and wind regimes, degree of insolation, humidity, etc.
	Terrain	Orography of the terrain (mountain, valley, plateau, swamp ...), rivers, volcanoes, etc.
	Flora and fauna	Vegetation type, type of ecosystem (mountain, jungle, savanna, steppe), forests, anthropogenic effects on the natural environment
	Human	Ethnic groups present in the area, types of settlements (centres and dispersion), type of housing, languages, customs, traditions, ages, number of women, many men, etc...
Economic activities (absolute and relative data) including jobs and income generated	Agriculture	Type of agriculture, type of crops, seasonality, etc.
	Livestock	Type of livestock farms, livestock type, uses, etc.
	Fishing	Type of fishing, uses, etc.
	Agri-food industry	Type of processed products, mode of commercialisation and operating regime (family, cooperative, micro-enterprise) etc.
	Craft workshops and manufacturing	Type of manufactured products, mode of commercialisation and operating regime (family, cooperative, micro-enterprise) etc.
	Third sector	Houses or stalls for food and / or drinks, lodgings, hostels, shops, etc.
	Financial institutions	Banks or existing rural banks, operating regime, loan terms, etc.
	Service workshops	Repair shops for cars and / or machinery, battery charging services, etc.
	Incomes	Per capita income, if possible broken down by activity or social strata. Number and percentage of the population under conditions of poverty and extreme poverty.
	Public investment	In services and infrastructures.
Public services	Health service	Health centres, hospitals. Number of doctors per inhabitant. Regime of collection of services and medicines.
	Drinking water and sanitation	Access to drinking water, water sanitation, sanitation systems.
	Education	Schools (primary, secondary and others). Number of teachers per child. Type of studies offered. Price (if applicable) etc.
	Community centres	Types of centre, activities that are developed in them, etc.

Field	Topic	Parameters
Public services	Energy	Energy infrastructures (electric grid, distribution of petrol and other fuels) and energy services (recharge of batteries or torches, etc.)
	Telecommunications	TV, radio, telephony, internet and telegraph and mail services.
	Waste management	If they exist, how they are treated and where.
	Water treatment	Sewage treatment plants.
	Communication routes	Roads (condition, type of terrain, connectivity with important political and economic centres), waterways, etc.
	Collective transport	Collective means of transport (type, frequency, capacity...)
Health	Diseases	Epidemiological study of the most frequent diseases, their frequency and their consequences. Endemic, occupational diseases, etc.
	Maternal and child health	Maternal health data (mortality or problems with childbirth, subsequent illnesses and complications) and children under 5 (mortality rate, morbidity, malnutrition, etc.).
	Life expectancy	Life expectancy at birth of the local population.
Education	Primary / Secondary	Percentage of children attending school, grade dropout (by sex and social status).
	Adults	Degree of adult illiteracy (by sex and social status), type of basic, middle and higher education (number of people by sex and social status).
Social	Family unit	Type of family unit. Number of people living together (men, women, children, elderly). Differentiated roles in the household between the components of the family unit (types of assigned tasks, time and effort, associated hazards and consequences).
	Gender	Differentiated roles between men and women, at the domestic level, in productive activities, in community decision-making and in political and social life.
	Community	Type of community organization and rules of coexistence and conflict resolution. Community or elderly councils or other collective bodies that make decisions at community level. People without political representation are influential in decision making (e.g. caciques or other powers).
	Organizations	Associations, committees, sectoral, professional, women, parents of students, immigrants, development, human rights, environmentalists, etc.
	Religions	Religions present in the area, number of followers, mutual relations, etc.
	Employment	Economically active population, unemployment rate, etc.

Field	Topic	Parameters
	Migrations	Immigration and emigration, qualitative and quantitative analysis. Influence on economic activities and on social organization.
Political-administrative	Political regime	Regime type, operating rules, etc.
	Institutions	Political institutions. Degree of connection with citizenship and corruption. Regional and local institutions. Where and who makes the decisions. Number of technicians and type of training.
	Public administration	Offices of public administration in the area: number, services provided, location, etc. Including police services
	Justice	Justice administration.

Appendix B

Village visit daily planning

Village visit dates: March 18 to 24, 2017

Day 1 – Saturday 18th March
- Contact local government office/Panchayat/Taluk/Collector's office: We have to get the data of load shedding hours based days/months/season or whichever time horizon is applicable. In addition, it will be perfect if we get the layout and data of existing distribution system/feeders for optimizing the local generator location later. Also check if there are areas which are totally un-electrified. Check the present connected load, number of houses etc.
- Go to Electrical Board or Substation for feeder voltage profile. These tasks may take some time so it should be started right from the beginning.
- Interact with villagers.
- Start house sampling. We cannot visit each and every house, so we have to select a sample that is a true representation of the whole village. Houses should be divided on the basis of income (high, medium and low, BPL, APL etc.) as well as size to study the connected as well as expected loads. Regarding load curve, you need to take both peak and off-peak demands (existing and expected), interacting with the people there and by measuring the connected loads in houses.

Day 2 – Sunday 19th March
- Continue house sampling.
- Start visiting houses, questionnaire.
- Interact with villagers.

Day 3 – Monday 20th March
- Contact local government office/Panchayat/Taluk/Collector's office.
- Go to Electrical Board or Substation.
- Continue house visits, questionnaire.
- Start identifying locations for installing wind/solar devices. Interact with villagers about this. Possible locations for installation of wind and solar power sources may be identified (not technical: we will do optimal siting and sizing of resources later) based on willingness of people/officials - roof top of public buildings/individual houses/shade-free areas - wind locations without barrier.

Day 4 – Tuesday 21st March
- Contact local government office/Panchayat/Taluk/Collector's office.

- Go to Electrical Board or Substation.
- Continue house visits, questionnaire.
- Continue identifying locations for installing wind/solar devices. Interact with villagers about this.
- Mid-Stay Assessment: summarizing the work done so far and what remains to do.

Day 5 – Wednesday 22nd March
- Continue identifying locations for installing wind/solar devices.
- Continue village interaction about this.
- Power quality assessment. We can just take the voltage profile at different locations of the feeder (farthest from the substation as worst case) - Though we are trying to get it from EB/SS, we should even measure it from houses.
- Check technical feasibility of community grid. Based on the data collected, feasibility of installing a community grid must be studied based on the available area, spread of houses and network topology of the existing distribution system.

Day 6 – Thursday 23rd March
- Continue power quality assessment.
- Check technical feasibility of community grid.
- Measurement/assessment of Hydro potential.

Day 7 – Friday 24th March
- Last minute things to do if necessary.
- Overall assessment of the work done during the village stay.
- Saying good bye to villagers: some event can be organized.

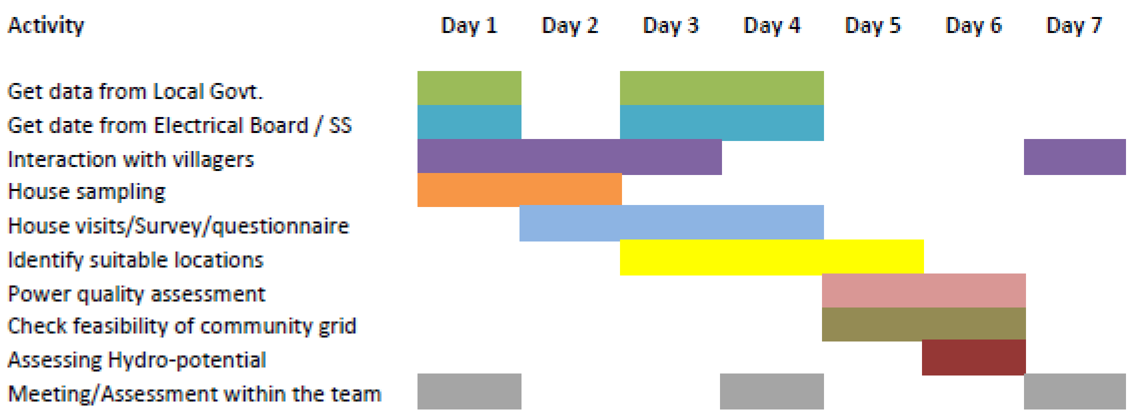

FIGURE B.1: Every day the team members should meet in the evening after field work to share their experience, and prepare for the next day. This way they can prepare next day's work and adjust daily planning depending on possible changing needs from the field.

Appendix C

Graphical representations of the data obtained during village visits

C.1 Voltage feeder profile

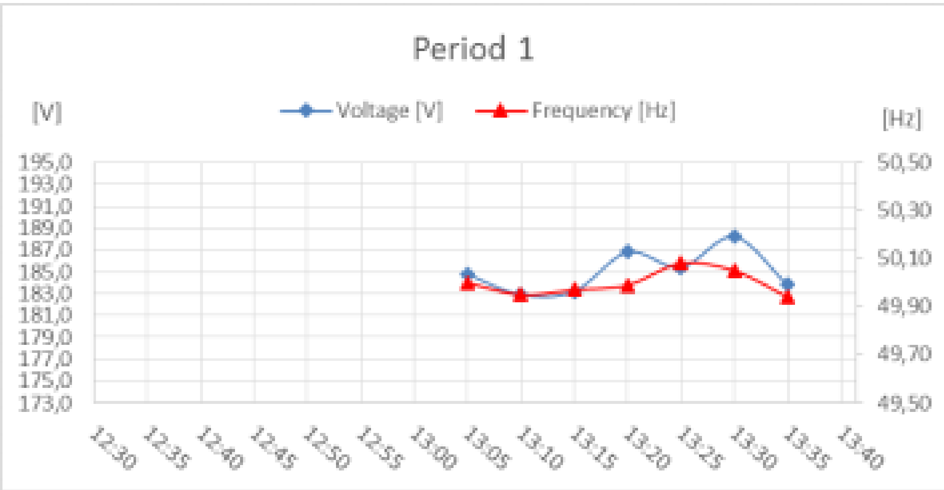

FIGURE C.1: First measurements of feeder voltage and frequency.

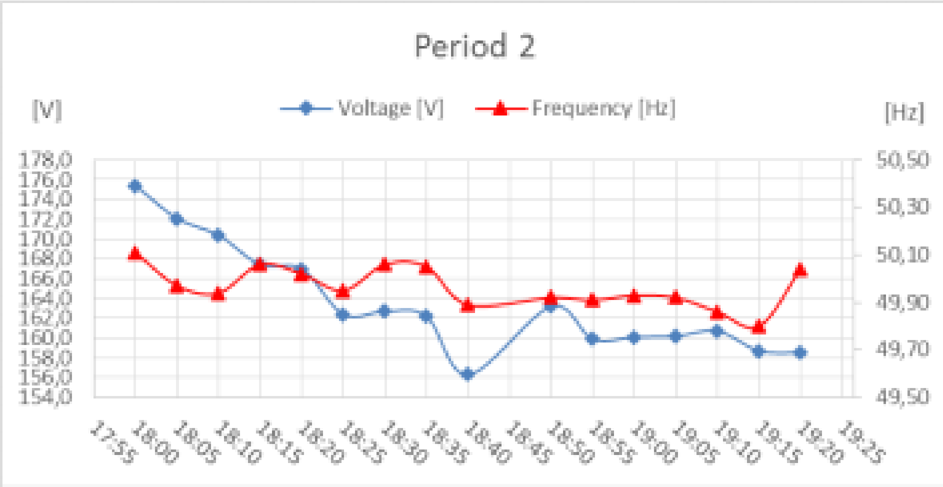

FIGURE C.2: Second measurements of feeder voltage and frequency.

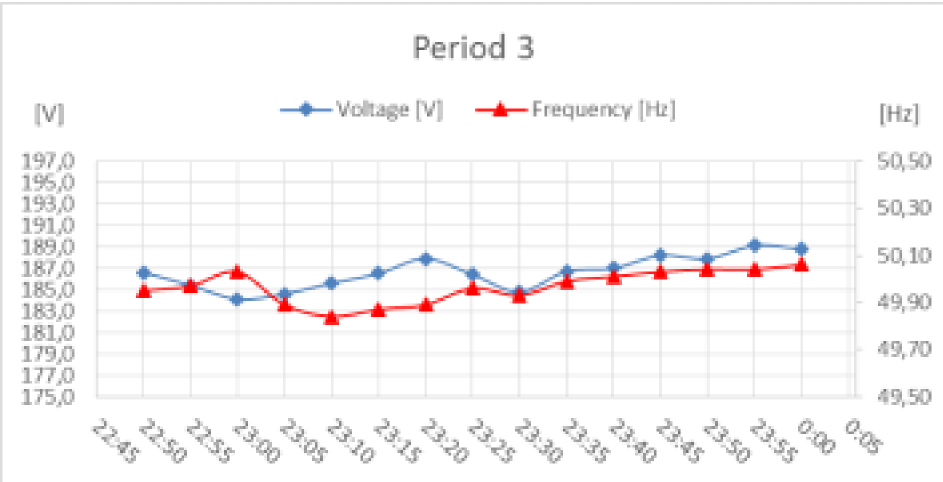

FIGURE C.3: Third measurements of feeder voltage and frequency.

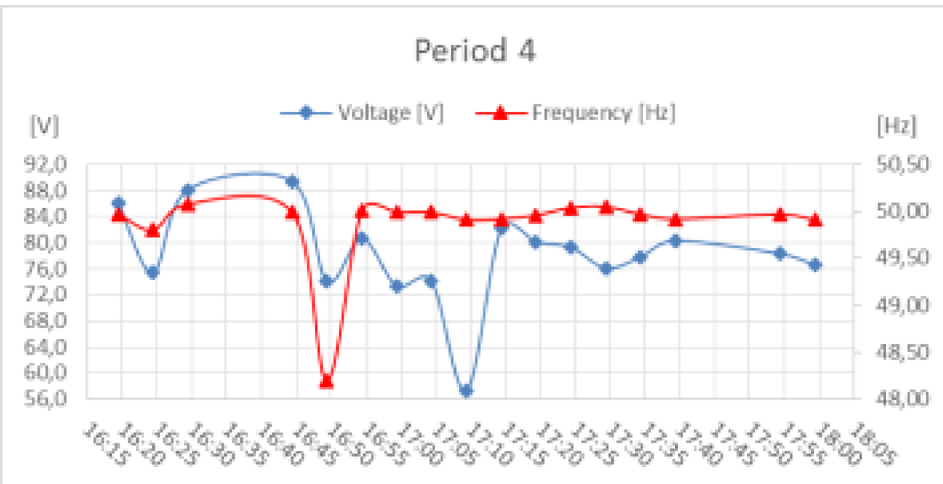

FIGURE C.4: Last measurements of feeder voltage and frequency.

Appendix D

Anchor - Business - Community month load profiles

Here are the different load profiles of the electricity demand in Dewgain for each month of the year.

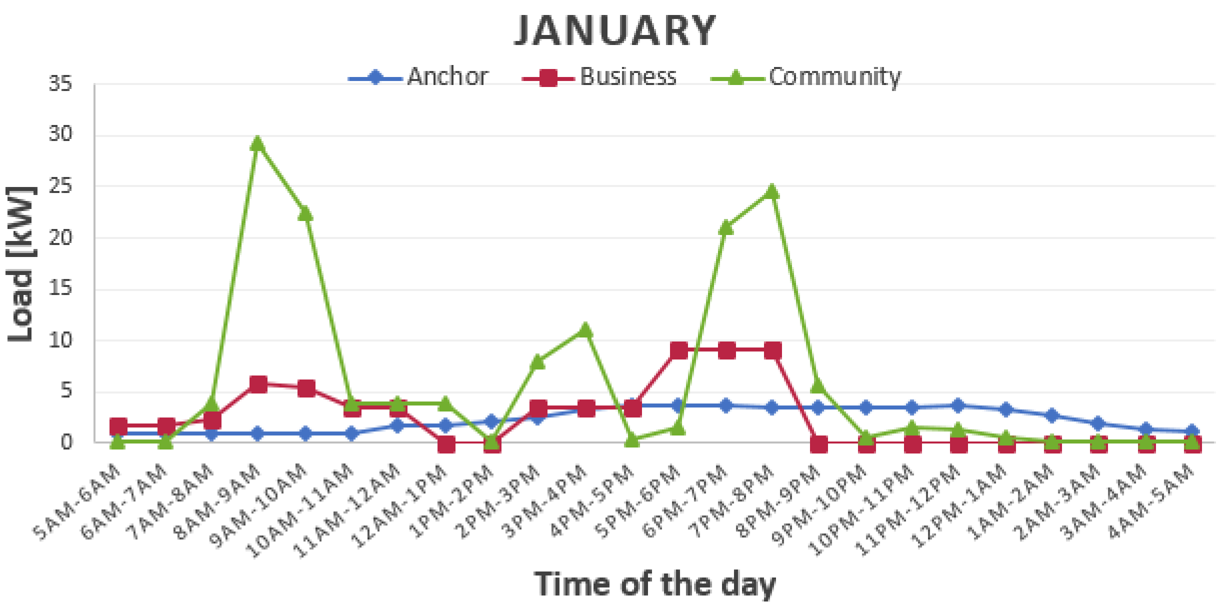

FIGURE D.1: The future demand of energy for each hour of the day during January.

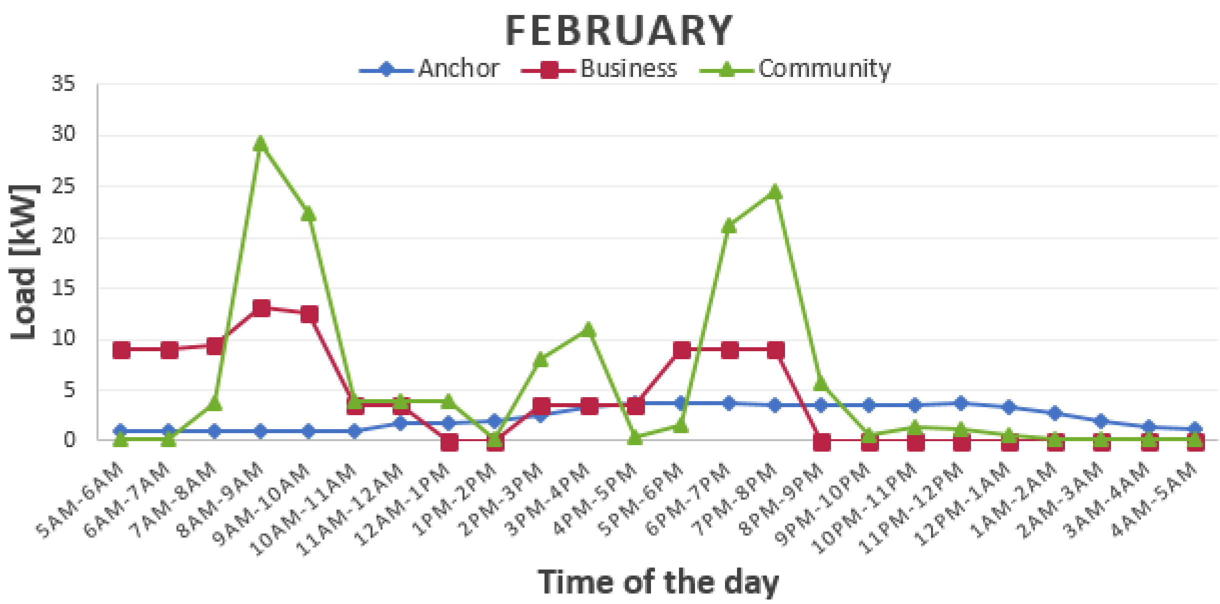

FIGURE D.2: The future demand of energy for each hour of the day during February.

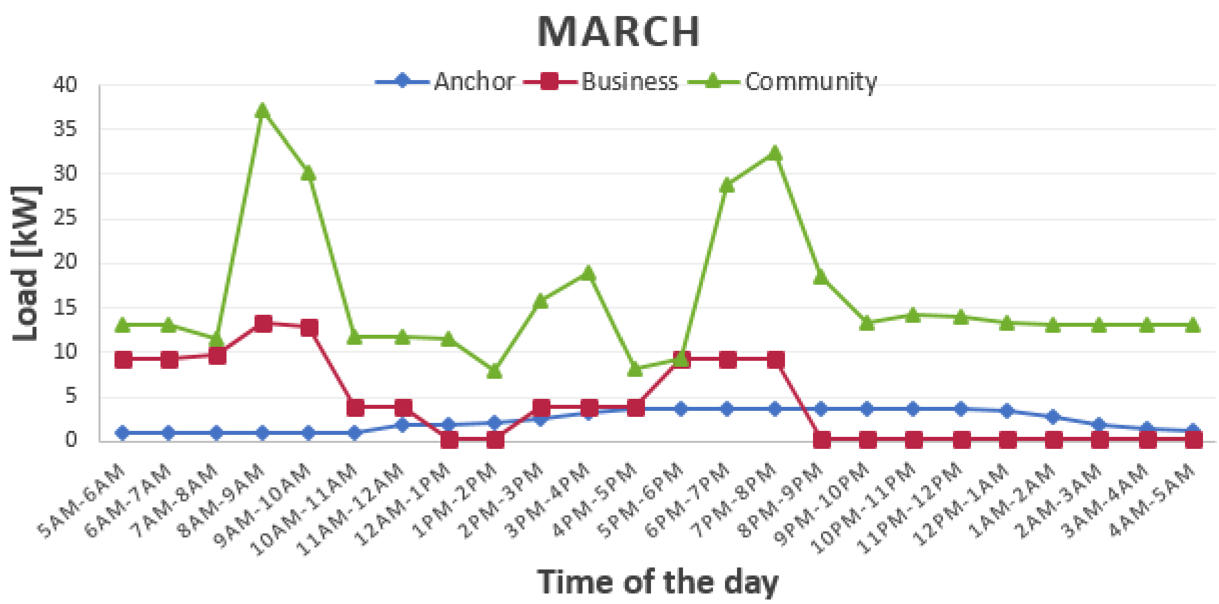

FIGURE D.3: The future demand of energy for each hour of the day during March.

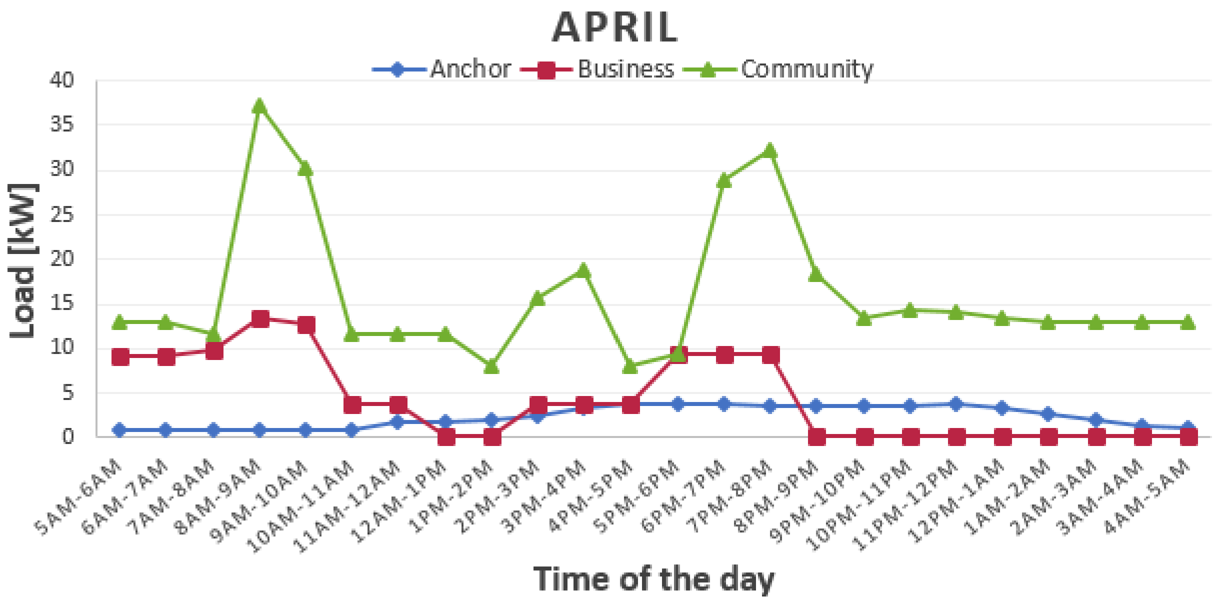

FIGURE D.4: The future demand of energy for each hour of the day during April.

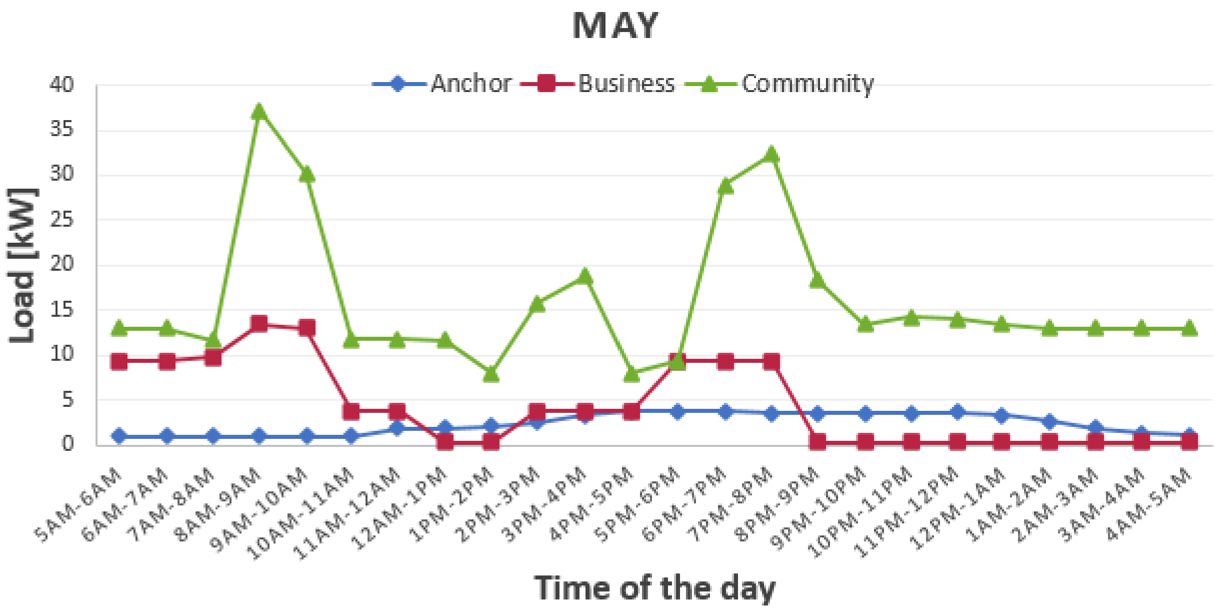

FIGURE D.5: The future demand of energy for each hour of the day during May.

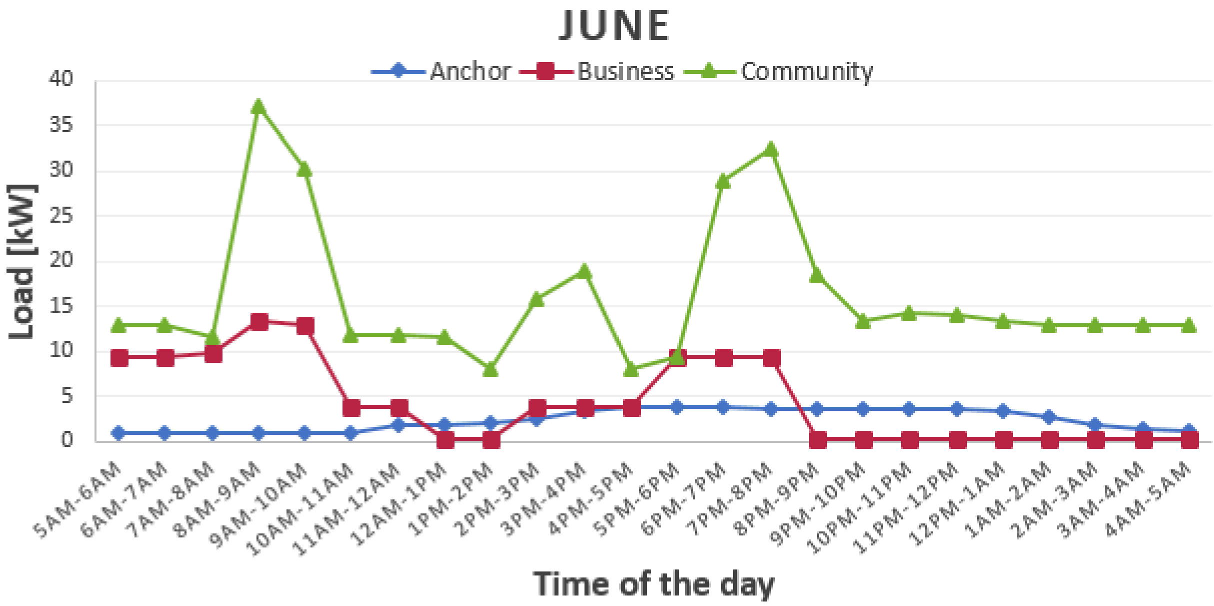

FIGURE D.6: The future demand of energy for each hour of the day during June.

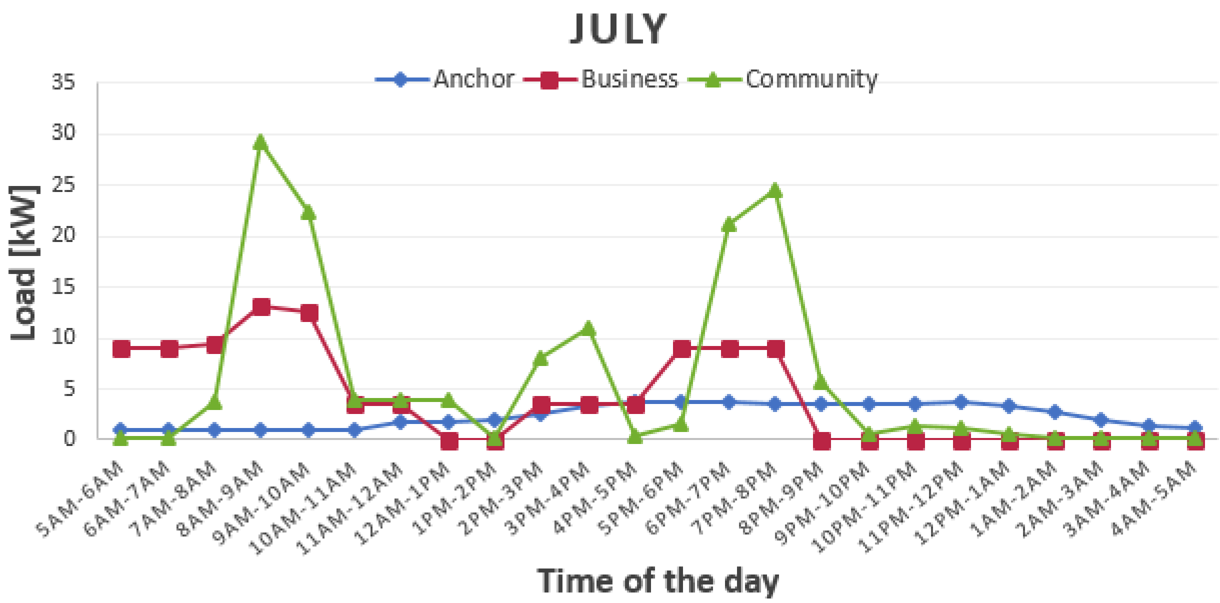

FIGURE D.7: The future demand of energy for each hour of the day during July.

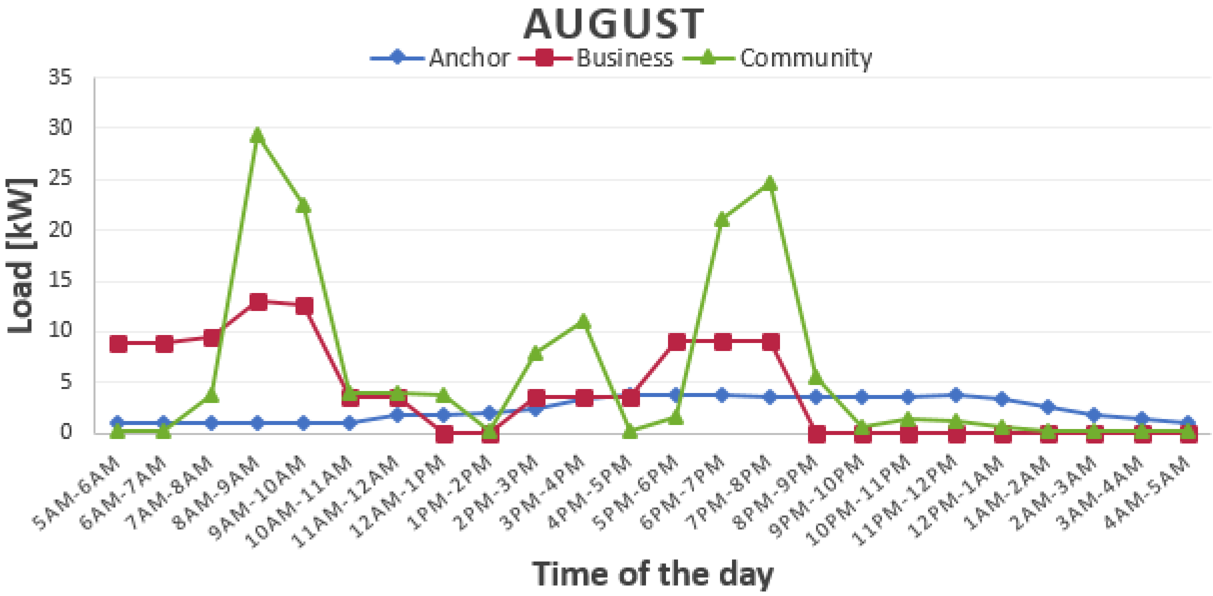

FIGURE D.8: The future demand of energy for each hour of the day during August.

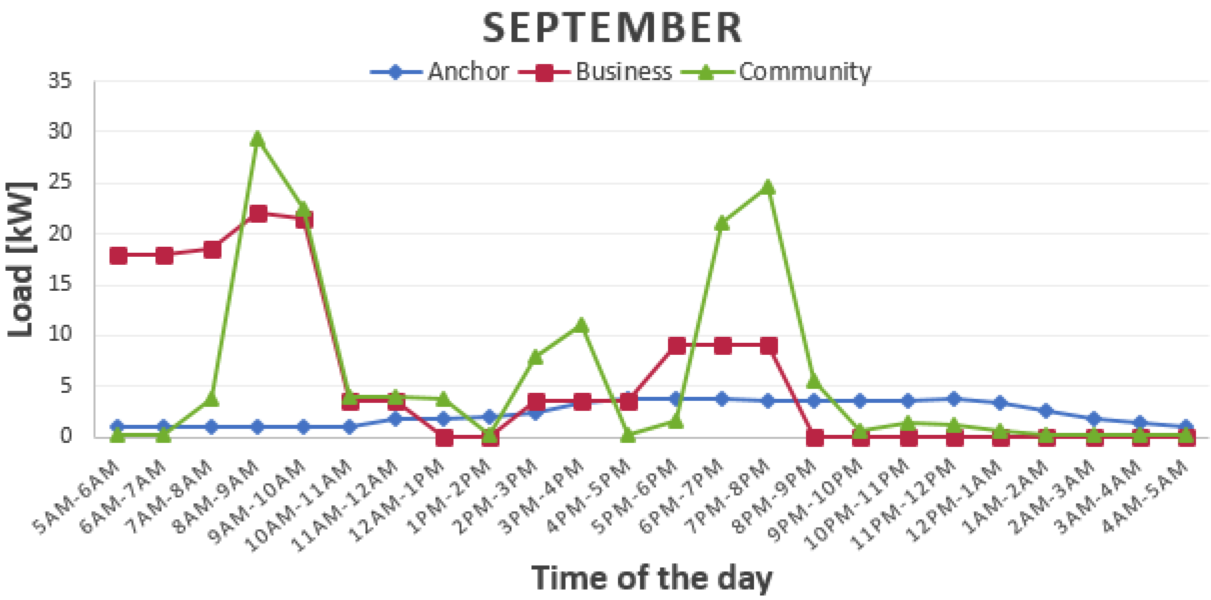

FIGURE D.9: The future demand of energy for each hour of the day during September.

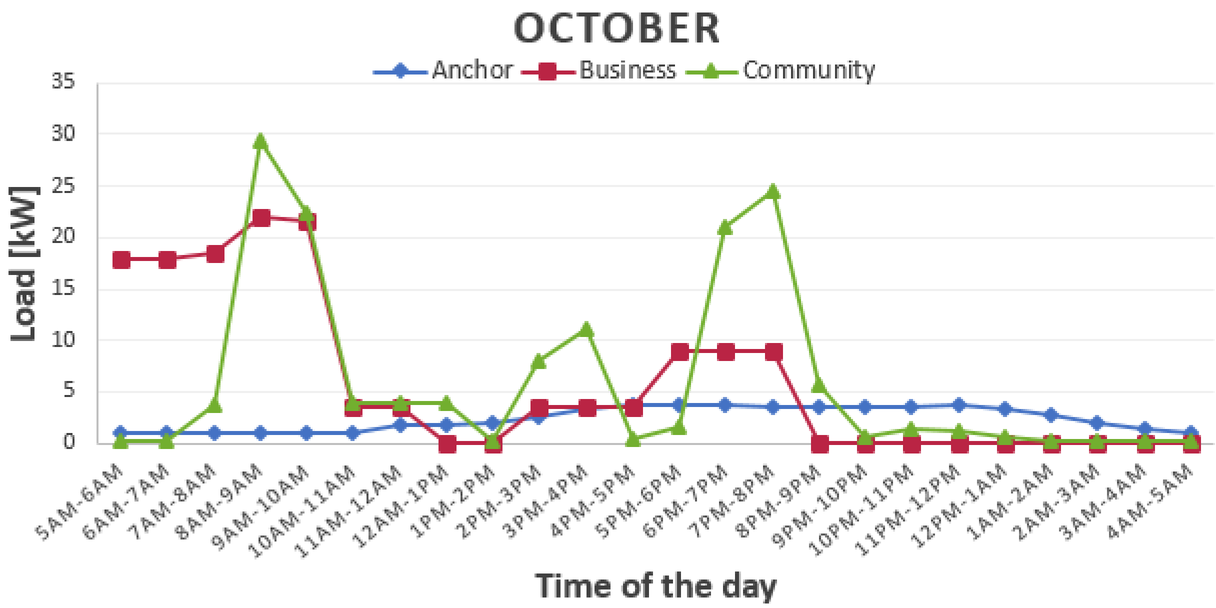

FIGURE D.10: The future demand of energy for each hour of the day during October.

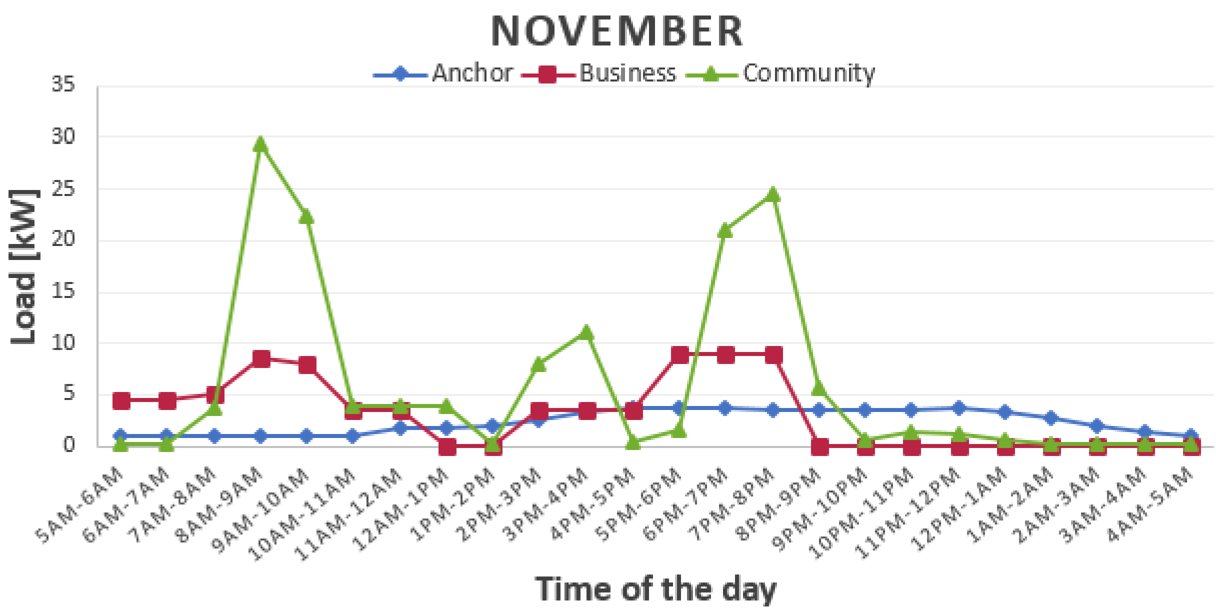

FIGURE D.11: The future demand of energy for each hour of the day during November.

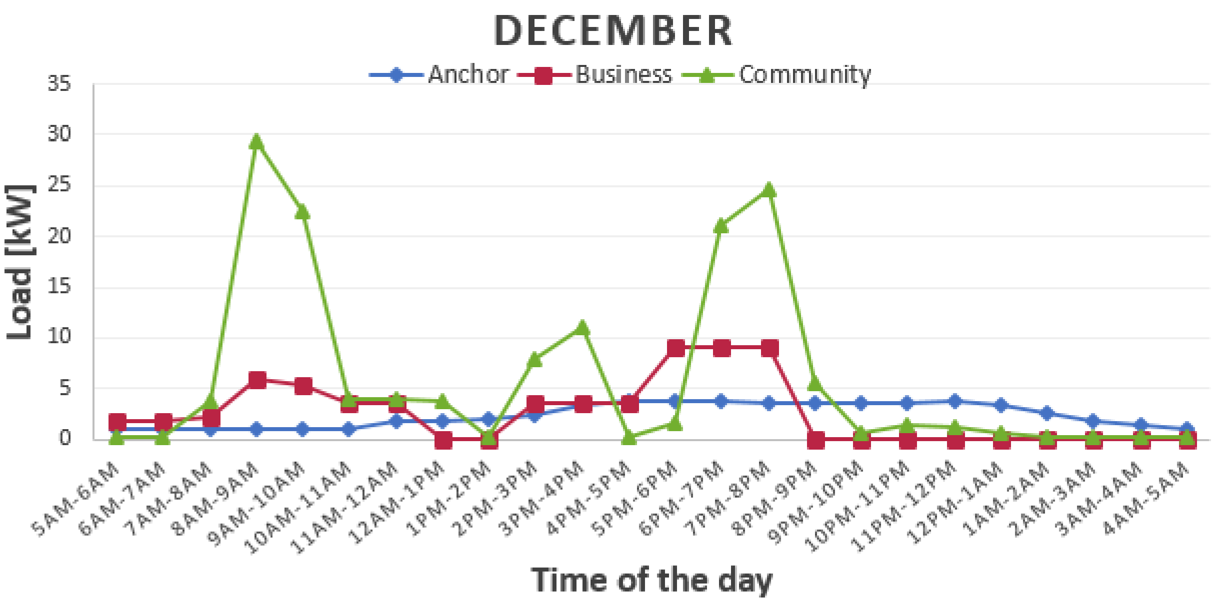

FIGURE D.12: The future demand of energy for each hour of the day during December.

Appendix E

Initial optimisation results

Overall project costs for each month and each generation combination are presented in the following graphics. Costs are presented realted to the BM generation percentage. The PV generation percentage of each combination is the complimentary to the BM generation, so between both technologies they achieve 100% of the generation.

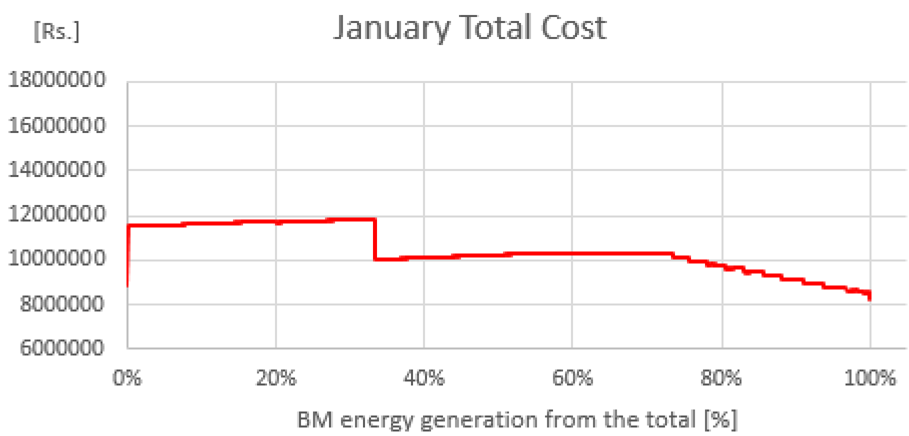

FIGURE E.1: Overall costs of the project, considering all the year as January.

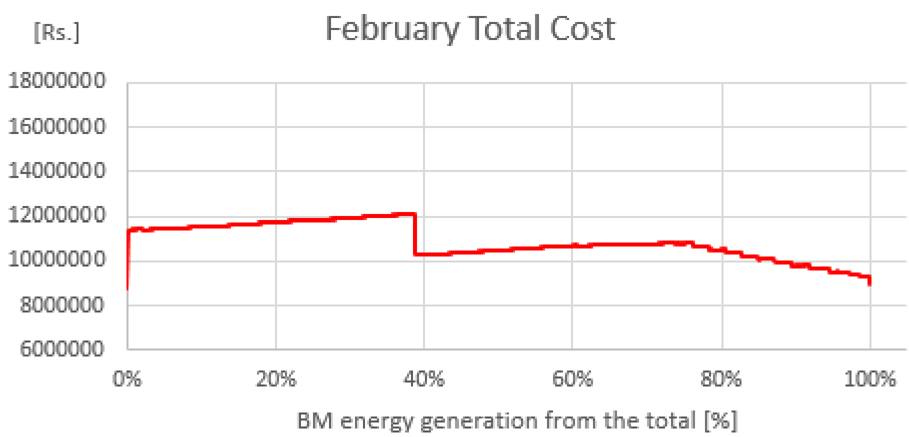

FIGURE E.2: Overall costs of the project, considering all the year as February.

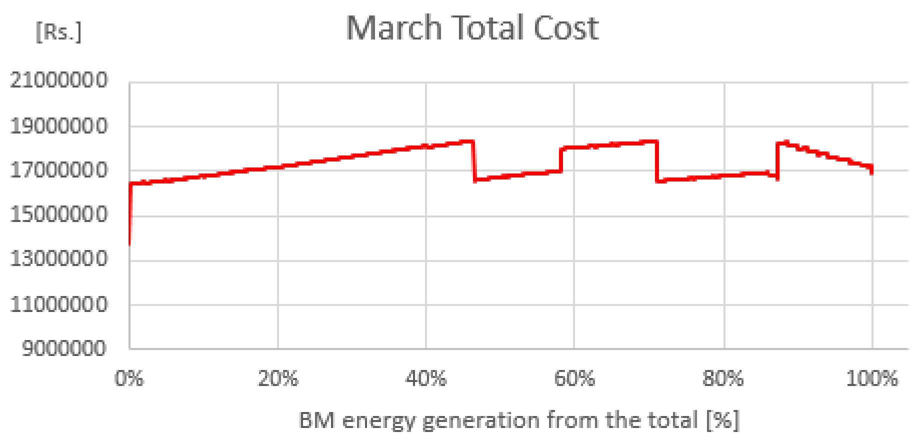

FIGURE E.3: Overall costs of the project, considering all the year as March.

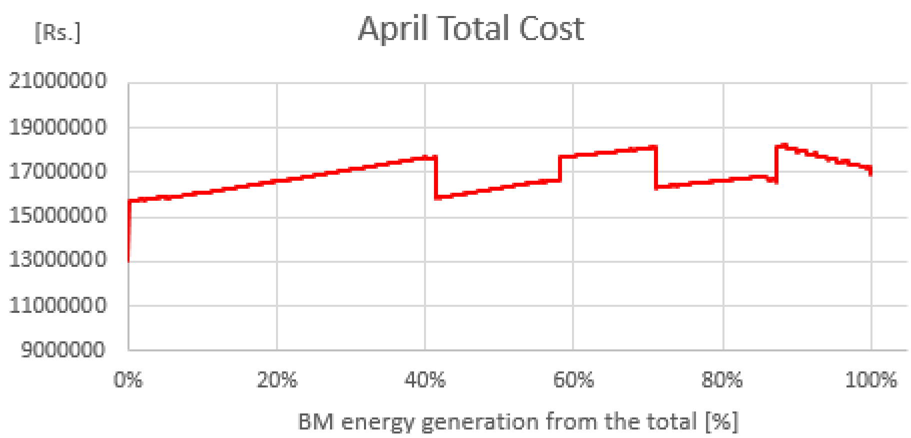

FIGURE E.4: Overall costs of the project, considering all the year as April.

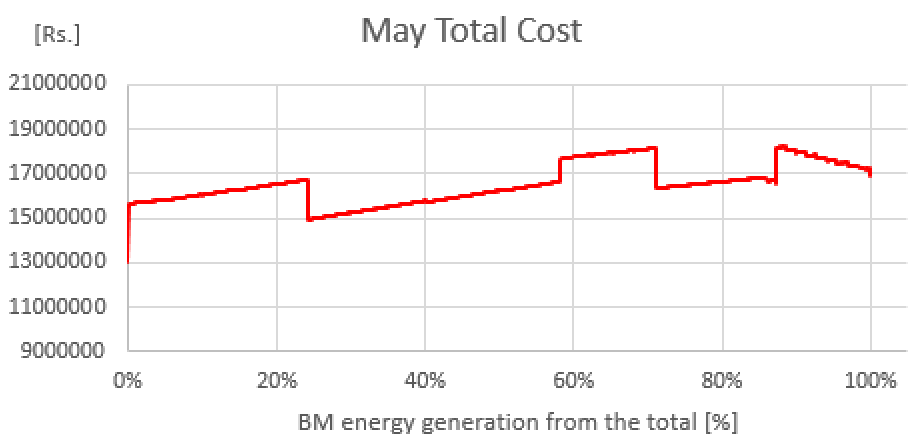

FIGURE E.5: Overall costs of the project, considering all the year as May.

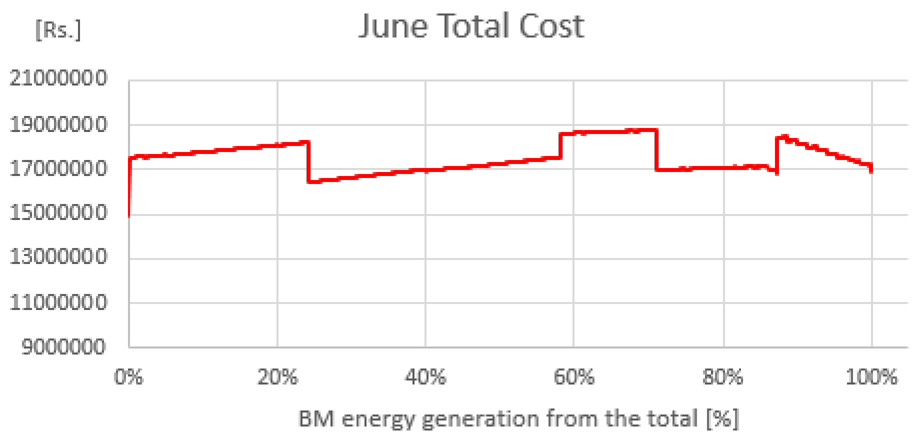

FIGURE E.6: Overall costs of the project, considering all the year as June.

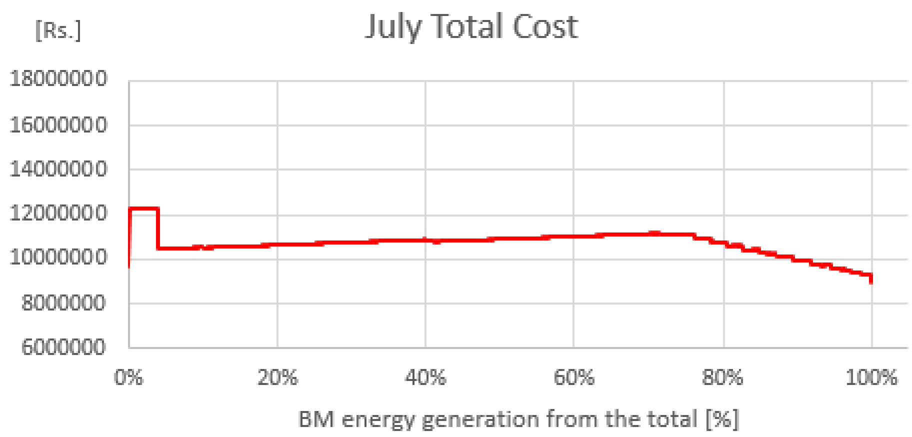

FIGURE E.7: Overall costs of the project, considering all the year as July.

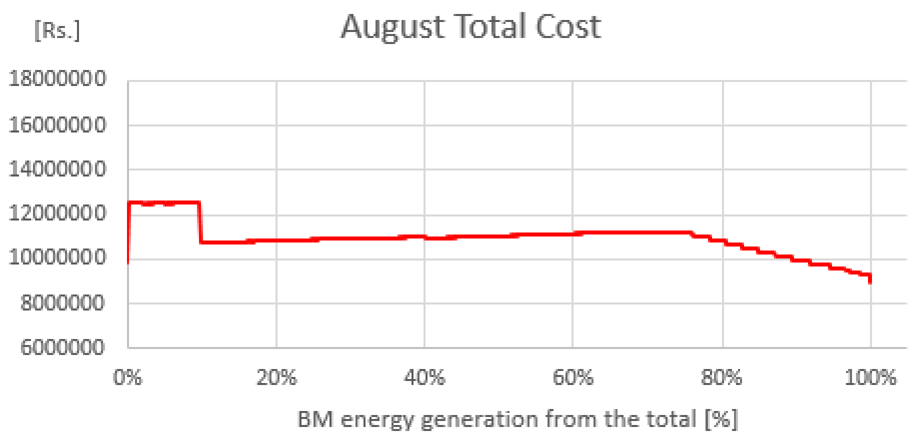

FIGURE E.8: Overall costs of the project, considering all the year as August.

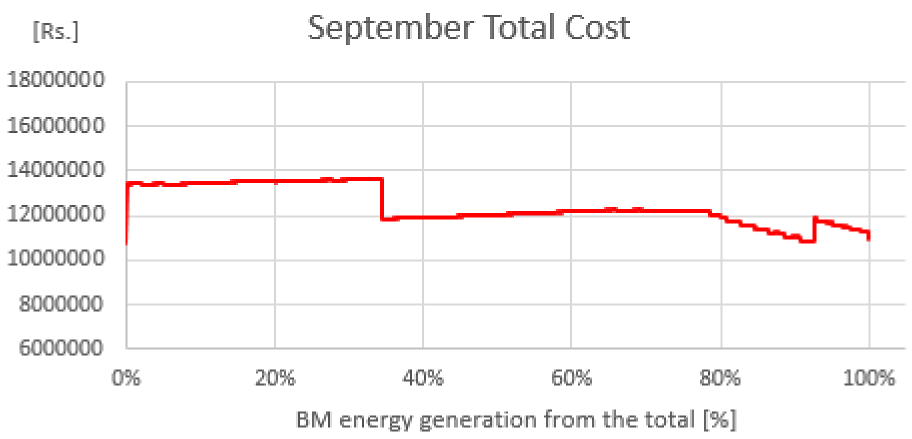

FIGURE E.9: Overall costs of the project, considering all the year as September.

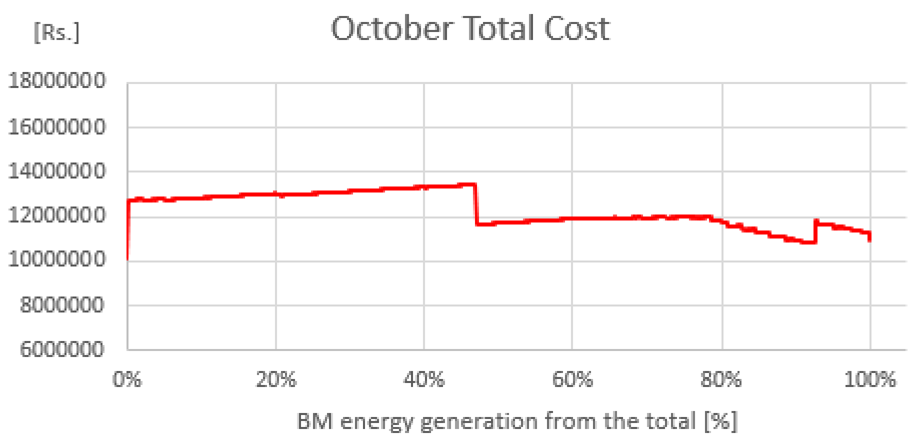

FIGURE E.10: Overall costs of the project, considering all the year as October.

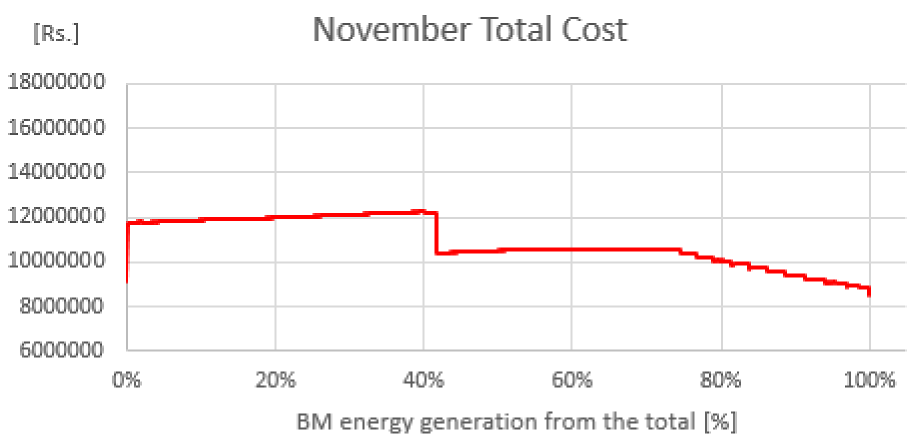

FIGURE E.11: Overall costs of the project, considering all the year as November.

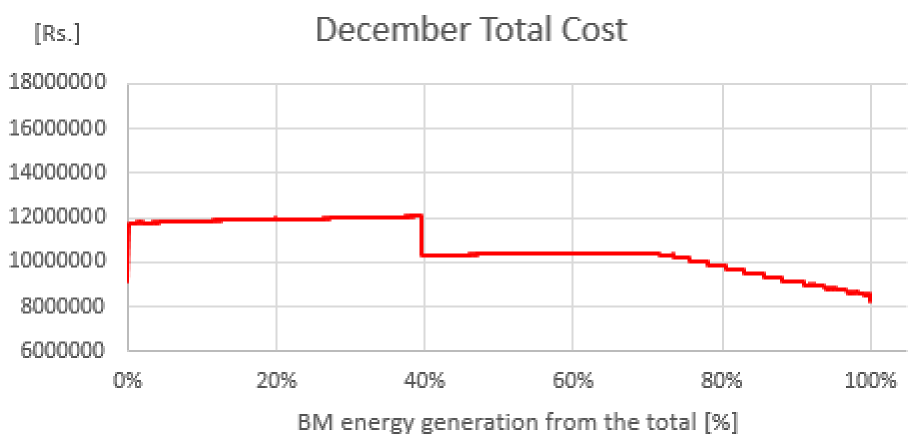

FIGURE E.12: Overall costs of the project, considering all the year as December.